National Environmental Research Program

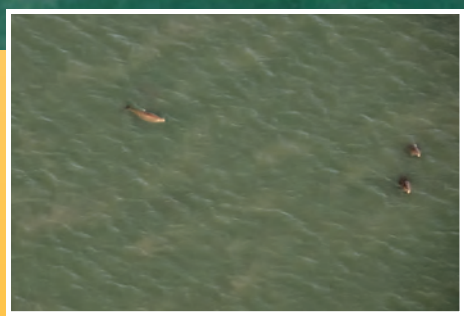
TROPICAL ECOSYSTEMS hub

Technical Report

Final Report to the Australian Marine Mammal Centre and the National Environmental Research Program

1 June 2012

Aerial survey of the urban coast of Queensland to evaluate the response of the dugong population to the widespread effects of the extreme weather events of the summer of 2010-11



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Supported by the Australian Government's National Environmental Research Program

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National Library of Australia Cataloguing-in-Publication entry:

978-1-921359-75-0

This report should be cited as:
Sobtzick, S., Hagihara, R., Grech, A., and Marsh, H (2012), *Aerial survey of the urban coast of Queensland to evaluate the response of the dugong population to the widespread effects of the extreme weather events of 2010-11.* Final Report to the Australian Marine Mammal Centre and the National Environmental Research Program. Published online by the Reef and Rainforest Research Centre Limited, Cairns (62pp.)

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Research Program (NERP) Tropical Ecosystems (TE) Hub.

The Tropical Ecosystems Hub is part of the Australian Government's Commonwealth National Environmental Research Program. The NERP TE Hub is administered in North Queensland by the Reef and Rainforest Research Centre Limited (RRRC). The NERP Tropical Ecosystem Hub addresses issues of concern for the management, conservation and sustainable use of the World Heritage listed Great Barrier Reef (GBR) and its catchments, tropical rainforests including the Wet Tropics World Heritage Area (WTWHA), and the terrestrial and marine assets underpinning resilient communities in the Torres Strait, through the generation and transfer of world-class research and shared knowledge.

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June 2012

Contents

List of Figures

List of Tables

Acronyms

GBR..................Great Barrier Reef
GBRMPA...........Great Barrier Reef Marine Park Authority
MPAs................Marine Protected Areas
NERP ....National Environmental Research Program
RRRC ....Reef and Rainforest Research Centre Limited
WTWHA ....Wet Tropics World Heritage Area

EXECUTIVE SUMMARY

(1) The urban coast of Queensland supports globally significant populations of dugongs and the importance of the Great Barrier Reef (GBR) Region for dugongs was a reason for its World Heritage listing. Coastal waters of this Region have been protected by the progressive establishment and upgrading of one of the world's most extensive networks of ecosystem-scale Marine Protected Areas (MPAs).

(2) Impacts of changes in global climate on dugong populations have not been well explored but mortality of dugongs due to storm events has been documented and intense tropical storms and rainfall events can negatively disrupt seagrass communities, adversely affecting dugong life history and reproductive rates.

(3) Severe weather event affecting the urban coast of Queensland in the summer of 2010/11 included the strongest La Niña weather pattern since 1973, major floods and Tropical Cyclones Tasha, Anthony and Yasi, all impacting the major dugong habitats on the urban coast of Queensland to varying degrees.

(4) In the light of the expected impacts of the extreme weather events of 2011 on dugong habitats, the objectives of the project were to: (1) inform dugong management along the urban coast of Queensland by continuing the time series of aerial surveys to monitor dugong distribution and abundance, and (2) document the impacts of the 2011 floods and cyclones on dugong distribution and abundance by comparing the results of the 2011 survey with the other surveys in the time series.

(5) The estimated total number of dugongs in Moreton Bay plus Hervey Bay was very similar to the combined estimates for 2005 (3001 ± 412) in 2005 compared with 2999 ± 128 in 2011 using the Marsh and Sinclair (1989a) methodology and 2538 ± 546 in 2005 compared with 2729 +599 in 2011 using the Pollock *et al*. (2006) methodology. The estimated size of the dugong population in the Southern GBR Region in November 2011 was the lowest since surveys began in 1986: 481 ± 43 using the methodology of Marsh and Sinclair (1989a), and 608 + 213 using the Pollock *et al*. (2006) methodology. These patterns were confirmed by the analyses of dugong density excluding the large herds; the 2011 dugong densities for Moreton Bay and Hervey Bay were not significantly different from the long-term averages, while the dugong density in the Southern GBR was significantly lower than for previous surveys.

(6) The proportion of calves in Hervey Bay (9.7%) and Moreton Bay (8.5%) were within the range expected for 'normal conditions' while no calves were seen in the Southern GBR during the 2011 survey.

(7) There was only a minor change between survey years in the overall proportion of high and very high density dugong planning units within 'protected' and 'unprotected' zones of the Great Barrier Reef Region's marine parks. However, a much lower proportion of high and very high density dugong planning units are highly protected in Moreton Bay than in the Southern GBR suggesting a need to reconsider the initiatives to protect dugongs in Moreton Bay. Given that the inshore seagrass meadows in Hervey Bay have been severely damaged by flood events on several occasions over the last 20 years, it would be prudent for the Queensland Government to increase the protection of the offshore seagrass beds in that region.

RECOMMENDATIONS

In order to reduce the risk of anthropogenic sources of dugong mortality along the urban coast of Queensland, we recommend the following initiatives:

(a) increasing the proportion of high and very high density dugong habitat in Moreton Bay and Hervey Bay that is zoned to protect dugongs;

(b) ensuring that the mirror zoning of the Queensland coastal marine park and the Great Barrier Reef Marine Park is maintained to provide co-ordinated protection of dugongs and their coastal habitats in the Great Barrier Reef region;

(c) introducing regional zoning of the East Coast Inshore Finfish Fishery to enable fishing practices to be tailored to individual areas to minimise interactions between fishers and dugongs and other megafauna;

(d) re-establishing a regional Indigenous group to co-ordinate the responses of Traditional Owners to extreme weather events in their Sea Country; and

(d) developing a strategic policy that favours the establishment of several well-managed mega-ports along the GBR coast, which collectively would pose substantially fewer risks to dugongs and their habitats than a larger number of smaller ports.

1.0 INTRODUCTION

The urban coast of Queensland Australia extends from Cooktown (15° 29'S, 145° 15'E) to the Queensland-New South Whales border (28° 10'S; 145 44'E). Over the last 30 years or so, the coastal waters of this region have been protected by the progressive establishment and upgrading of one of the world's most extensive network of ecosystem-scale Marine Protected Areas (MPAs) including part of the Cairns Section and the Southern and Central Sections of the Great Barrier Reef Marine Park (e.g. Fernandes *et al*., 2005), the associated sections of the Great Barrier Reef Coast Marine Park (EPA, 2006a), the Great Sandy Marine Park (incorporating Hervey Bay; EPA, 2006b) and the Moreton Bay Marine Park (EPA, 2006c). These MPAs have developed in conjunction with other management initiatives such as fisheries management plans, arrangements to mange Indigenous hunting (Marsh, 1996; Havemann *et al*., 2005) and arrangements to minimize the impact of terrestrial runoff on the seagrass communities on which dugongs depend (Reef Water Quality Protection Plan http://www.environment.gov.au/coasts/pollution/reef/index.html).

The region supports globally significant populations of the dugong, Dugong dugon, a coastal marine mammal that feeds mainly on seagrasses (Marsh *et al*., 2011). The significance of the Great Barrier Reef (GBR) Region for dugongs was a reason for its World Heritage listing (GBRMPA, 1981). Thus the status and trends in the distribution and abundance of dugongs is critical information for the management of the World Heritage Area (GBRMPA, 2005) and the associated network of MPAs (Marsh, 2000; Chilvers *et al*., 2005).

The impacts of changes in global climate on dugong populations have not been well explored and are open to conjecture (see Lawler *et al*. 2007; Marsh *et al*. 2011). Nonetheless, global climate change is likely to result in increased intensity and perhaps frequency of severe storms (Webster *et al*. 2005; Florida Oceans and Coastal Council 2009; Bender *et al*. 2010). Mortality of dugongs due to storm events has been well documented, including strandings in receding high waters (Heinsohn and Spain 1974; Marsh 1989). Intense tropical storms and rainfall events can also negatively disrupt seagrass communities (Short and Neckles 1999), with seagrass diebacks. Seagrasses are highly dependent on water clarity, and run-off and other factors that increase turbidity will negatively impact important dugong food sources (Short and Neckles 1999; Orth *et al*. 2006).

The life history and reproductive rate of female dugongs are adversely affected by seagrass loss. Dugongs eat algae and more fibrous species of seagrass in greater quantities when seagrass is in short supply (Spain and Heinsohn 1973; Marsh *et al*. 1982, 2011) and are not well adapted to using algae or fibrous seagrasses as a food source (Marsh *et al*. 1982; Marsh *et al*. 2011).

The loss of more than 1000 km^2 of seagrass in Hervey Bay in South-eastern Queensland in 1992 following two floods and a cyclone demonstrated that, when their food supply fails, individual dugongs variously exhibit one of two functional responses. Dugongs may emigrate from the affected area or remain, consuming any remaining seagrass and low-quality food such as algae, risking mortality and postpone breeding. Twenty-one months after the extreme weather in early 1992, the regional dugong population was reduced to an estimated 500 $\pm$ SE 126 animals from an estimated 2206 $\pm$ SE 420 animals in 1988 (Preen and Marsh 1995). Although unprecedented numbers of dugong carcasses were found along 1500 km of coastline in 1992 and 1993, the dugong population of Hervey Bay recovered too fast for this population reduction to be caused by mortality in the absence of substantial immigration, reaching 2547 ± SE 410 in 2005 (Marsh and Lawler 2007). The dugongs that stayed in Hervey Bay delayed breeding and/or suffered high calf mortality. The proportion of the dugong population classified as calves during the aerial surveys declined from 22% in 1988 to 2.2% in 1993 and 1.5% in 1994 (Preen and Marsh 1995; Marsh and Corkeron 1997) suggesting that the impacts of habitat loss on fecundity/calf survivorship may last several years. The percentage of calves then increased concomitant with the seagrass recovery, reaching 14.5% in 1999, 8.2% in 2001 (despite a more localised flood event that destroyed intertidal seagrasses in 1999, Campbell and McKenzie 2004) and 7.2% in 2005 (Marsh and Lawler 2001; Grayson *et al*. 2008).

The data from Hervey Bay demonstrate that dugong calf counts are impacted by local weather events outside the El Niño/La Niña cycle which has regional scale impacts. Grayson *et al*. (2008) used the aerial survey records collected in Australia since the mid-1970s to quantify spatial and temporal patterns using percentage calf counts as a surrogate measure of dugong fecundity/calf survivorship. They used generalised linear models to investigate if changes in percentage calf counts are associated with long-term weather indices. Large temporal and spatial differences were evident in the proportion of calves seen during aerial surveys. In regions that were comprehensively surveyed, the proportion of calves ranged from 0.2% in the northern Great Barrier Reef Region in 1978 to 22% in Hervey Bay in 1988 and 1992. The modelling provided evidence that calf counts were affected by the El Niño/La Niña cycle lagged by two years in the northern Great Barrier Reef Region, presumably a result of: (1) the negative impact of increased turbidity on some of the coastal seagrass species eaten by dugongs (Preen *et al*. 1995; Longstaff and Dennison 1999), (2) the need for dugongs to be in good condition prior to and during pregnancy and lactation (Kwan 2002; Marsh and Kwan 2008), and (3) the life history of the dugong with pregnancy lasting 12–14 months and lactation up to about 18 months or more (Marsh *et al*. 2011). The analysis suggested that similar relationships exist for some other regions, but the data are not yet adequate to confirm them statistically (Type 2 error). The negative impact on dugong life history of the loss of coastal seagrass associated with exceptionally high rainfall and other extreme weather events is of major concern when considering the impact of climate change on dugongs.

The inshore seagrass meadows of the urban Great Barrier Reef Region were declared to be vulnerable in 2009 with declining trajectories, particularly south of Cairns (McKenzie *et al*. 2012). This situation was exacerbated by the spatial extent of the extreme weather events on the urban coast of Queensland in the summer of 2010/11. Bureau of Meteorology records indicate that the La Niña weather pattern was the strongest since 1973 http://www.bom.gov.au/climate/current/annual/qld/summary.shtml. Heavy rainfall fell across central and southern Queensland River catchments in January 2011 as a result of Tropical Cyclone Tasha which crossed the coast south of Cairns on 24th December combined with a trough. Three quarters of the state was declared a disaster zone on 11th January 2011. Tropical Cyclone Anthony crossed the coast near Bowen on the 30th January followed by Severe Tropical Cyclone Yasi (marginal Category 5) which made landfall on the southern tropical coast near Mission Beach early on 3rd February 2011. Autumn was the wettest since 1990 and included the wettest March on record.

These events impacted all the major dugong habitats on the urban coast of Queensland to varying degrees (McKenzie *et al*. 2012). Thus dugongs were likely to have limited options to find food south of Cape York and the number of dugong mortalities recorded in Strandnet, the Queensland Marine Wildlife Mortality Database was the highest ever recorded (Col Limpus per comm. 2012). Satellite tracking indicates that dugongs can move hundreds of kilometres in a few days (Sheppard *et al*. 2006) but the frequency with which such movements are likely to occur is not known. Matrilinearly transmitted learned behaviour, commonly known as tradition, seems to play a large role in determining use of space and migratory habits of Florida manatees (Marsh *et al*. 2011) and possibly dugongs (Anderson 1981; Sheppard *et al*. 2006) and may have limited the response of dugongs to the widespread habitat loss over more than 2000 km of coastline.

Dugongs have been surveyed along the urban coast of Queensland using standard techniques since the mid-1980s (Table 1). These surveys have provided long-term information on the distribution and abundance of dugongs. In the light of the expected impacts of the extreme weather events of 2011 on dugong habitats, the objectives of the project were to: (1) inform dugong management along the urban coast of Queensland by continuing the time series of aerial surveys to monitor dugong distribution and abundance, and (2) document the impacts of the 2011 floods and cyclones on dugong distribution and abundance by comparing the results of the 2011 survey with the other surveys in the time series.

Table 1: Details of the aerial surveys conducted prior to 2011.

Date of survey	Reference	Date of survey	Reference
Moreton Bay		Southern and Central Section of the GBRMP	
August 1988	Marsh & Saalfeld, 1990 a and b, unpublished	November 1986	Marsh & Saalfeld, 1990 a and b
December 1995	Lanyon, 2003[1]	November 1987	
December 2000	Lawler, 2002, unpublished	November 1992	Marsh *et al.*, 1994, unpublished
April & November 2001	Lawler, 2002, unpublished	November 1994	Marsh *et al.*, 1996, unpublished
November 2005	Marsh & Lawler, 2007	November 1999	Marsh & Lawler, 2001
Hervey Bay		November 2005	Marsh & Lawler, 2007
August 1988	Marsh & Saalfeld, 1990 a and b, unpublished; Preen & Marsh, 1995	Cairns Section of the GBRMP	
November1992		November 1987	Marsh & Saalfeld, 1990 a
November 1993			
November 1994	Marsh *et al.*, 1996, unpublished	November 2000	Marsh & Lawler, 2001
November 1999	Marsh & Lawler, 2001	November 2005	Marsh & Lawler, 2007
April & November 2001	Lawler, 2002, unpublished		
November 2005	Marsh & Lawler, 2007		

[1]Lanyon conducted a series of surveys in 1995. We used the results of the December survey to minimise seasonal differences.

2.0 METHODS

2.1 Preparation and timing of survey

Due to the large scale of the survey, two teams (Northern Team and Southern Team) were assembled to work independently in different regions. Two training workshops, one in Townsville (1^{st} – 3^{rd} November 2011) and one in Brisbane (4^{th} and 5^{th} November 2011), were conducted with members of the survey teams prior to the survey. The Northern Team conducted additional training flights during the survey after the change-over of some observers. The Northern Team started surveying on November 4^{th} 2011; the Southern Team on November 6^{th} 2011. The entire survey was successfully completed on December 1^{st}, 2011.

2.2 Survey design

The survey area was the east coast of Queensland from just north of Port Douglas (16°14' S) to the New South Wales border (28°10' S) (see Figures 1 and 2). Transects were based on previous surveys with the following changes:

(1) Some offshore transects were truncated if they extended out into areas where no dugongs had been sighted on previous surveys.

(2) Transects off the east coast of the Palm Island group, the Whitsunday Islands, Fraser Island, Moreton Island, North and South Stradbroke Island, as well as the coastline between Hervey Bay and Moreton Bay and between Moreton Bay and the New South Wales border (all areas where no dugongs were sighted on previous surveys) were flown parallel to the coastline as opposed to the East-West orientation of the majority of other transects.

2.3 Survey methodology

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

Transects 200 m wide on the water surface on each side of the aircraft were demarcated using fibreglass rods attached to artificial wing struts. Transects were divided into four horizontal sub-strips (very high, high, medium and low) which were marked on the wing struts. Two tandem teams of observers on each side of the aircraft scanned the transects and recorded their sightings onto separate tracks of an audio recorder. The two members of a tandem team were independent 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. The sightings of the tandem observers were also used to calculate survey specific correction factions for perception bias for each side of the aircraft as outlined below.

2.4 Estimating the size of the dugong population and dugong density

Two methods were used to calculate standardised estimates of relative dugong abundance: (1) Marsh and Sinclair (1989a) which has been used in dugong aerial surveys since 1986; and (2) Pollock *et al*. (2006) which has been used in the recent surveys. Both methods attempt to correct for availability bias (animals not available to observers because of water turbidity), and perception bias (animals visible in the survey transect but missed by observers; Marsh & Sinclair, 1989a). We believe the methodology of Pollock *et al*. (2006) is superior because the correction for availability bias addresses the spatial heterogeneity in sighting conditions for each sighting whereas the Marsh and Sinclair (1989a) method averages conditions within surveys and only corrects for differences in availability bias between surveys. All population estimates are provided ± standard errors.

2.5 Statistical analyses

Comparison of group size

We used Kruskal Wallis one-way ANOVA to examine differences of group size among Moreton Bay, Hervey Bay and the southern GBR Regions because transformation did not normalize distribution of the data.

Distribution of dugongs across bathymetric ranges

We used $\chi 2$ goodness-of-fit test to examine whether the distribution of dugongs across variable water depths differed in the 2011 surveys from previous surveys conducted in each survey region. The bathymetric model was generated by Lewis (2001). Each sighting was initially classified into a 5-m bathymetric bin. Because observations in some cells were small, we combined some depth categories to meet the assumptions of $\chi 2$ tests (Moreton Bay: < 5 m, > 5 m; Hervey Bay: < 5 m, 5 to < 10 m, 10 to < 15 m, ≥ 15 m; Shoalwater Bay: < 5 m, > 5 m; Hinchinbrook Island: < 5 m, 5 to < 10 m and ≥ 10 m). Separate tests were performed for the data from Moreton Bay, Hervey Bay, Shoalwater Bay and Hinchinbrook Island.

Comparison of dugong density with surveys since 1986

Differences in dugong density from surveys conducted since 1986 were examined for eleven blocks and the data generated by the methodology of Marsh & Sinclair (1989a): Blocks MB3, MB4 and MB6 (Moreton Bay Region), Blocks HB1, HB2, HB3 and HB4 (Hervey Bay Region), Blocks C6 (Upstart Bay), C10 and C11 (Hinchinbrook area) and S5 (Shoalwater Bay). Separate statistical tests were conducted for each region. For Moreton Bay, we examined dugong density using the data from the 2000, 2001, 2005 and 2011 surveys; Hervey Bay from 1994, 2000, 2001, 2005 and 2011, and Southern GBR from 1986, 1992, 1994, 1999, 2005 and 2011. Because distribution and abundance of dugongs differed between summer and winter (Lawler 2002, Lanyon 2003, Gales *et al*. 2004, Holley *et al*. 2006), we limited our analyses to surveys which were conducted during summer. Similar comparisons were made for the 2005 and 2011 surveys only using the density data estimated using the Pollock *et al*. (2006) methodology.

Statistical analyses followed Marsh and Lawler (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. We used results from transects that were flown in all the surveys years we examined. F-ratios were calculated from the split-plot fixed model using transect as subplots of block. We used Monte Carlo Markov Chains (MCMC) to obtain statistical significance based on the estimated mixed-effects model parameters. The model used the restricted maximum likelihood estimation. We transformed dugong density (ln (y + 0.1)) to ensure homogeneous mean-variance components and used the transformed density as a response variable. Where appropriate, unplanned comparisons were performed to detect significant difference in the dugong density between blocks.

We used a fixed effects split-plot ANOVA to examine the differences in transformed dugong density (ln (y + 0.1)) between 2005 and 2011 for data generated by the Pollock *et al*. (2006) methodology. The same 11 blocks were examined for this analysis.

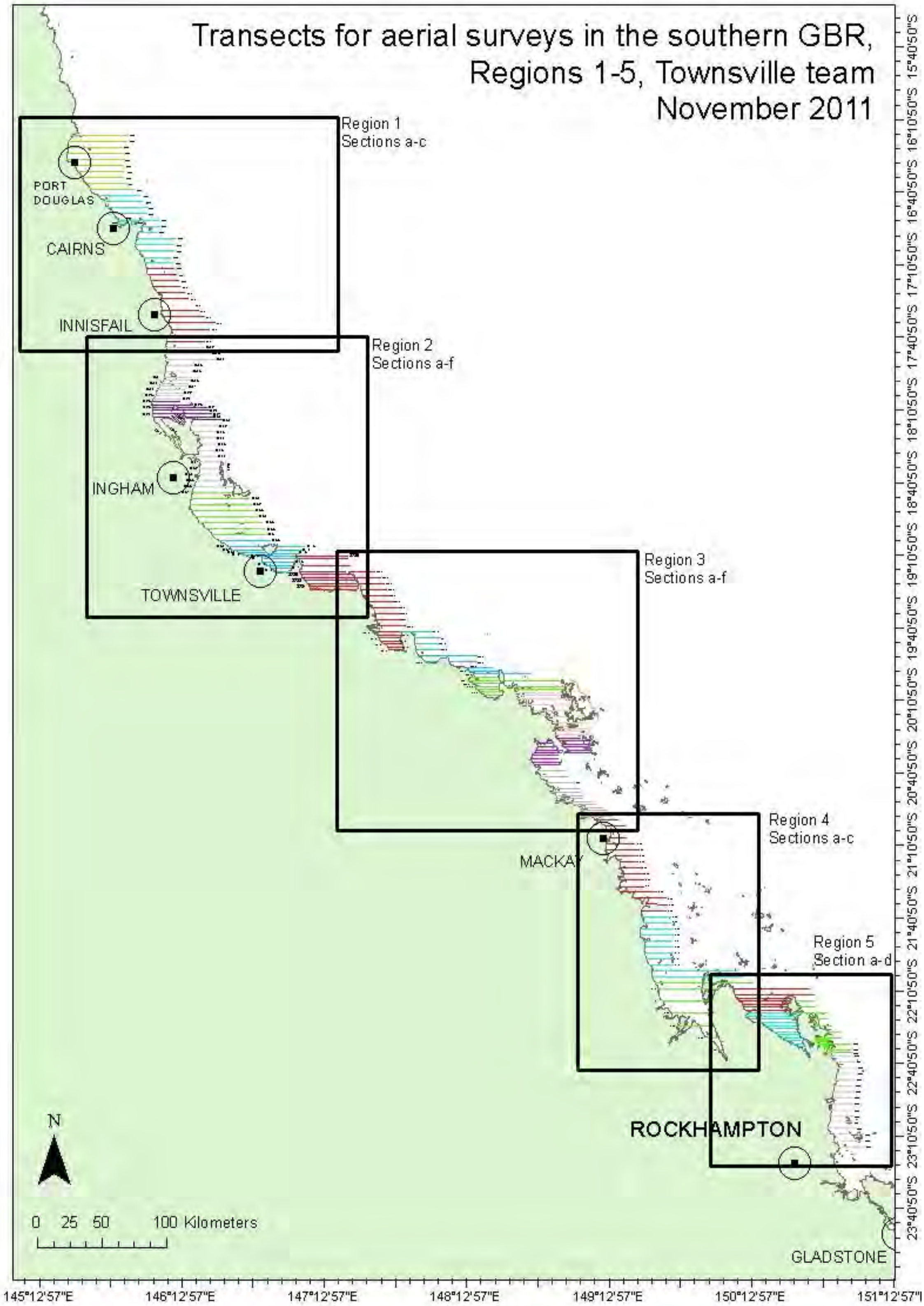

Figure 1: Map showing the east coast of Queensland with transects flow in the November 2011 survey from approximately Rockhampton north. Black boxes mark individual survey regions (Southern Great Barrier Reef Regions 1-5).

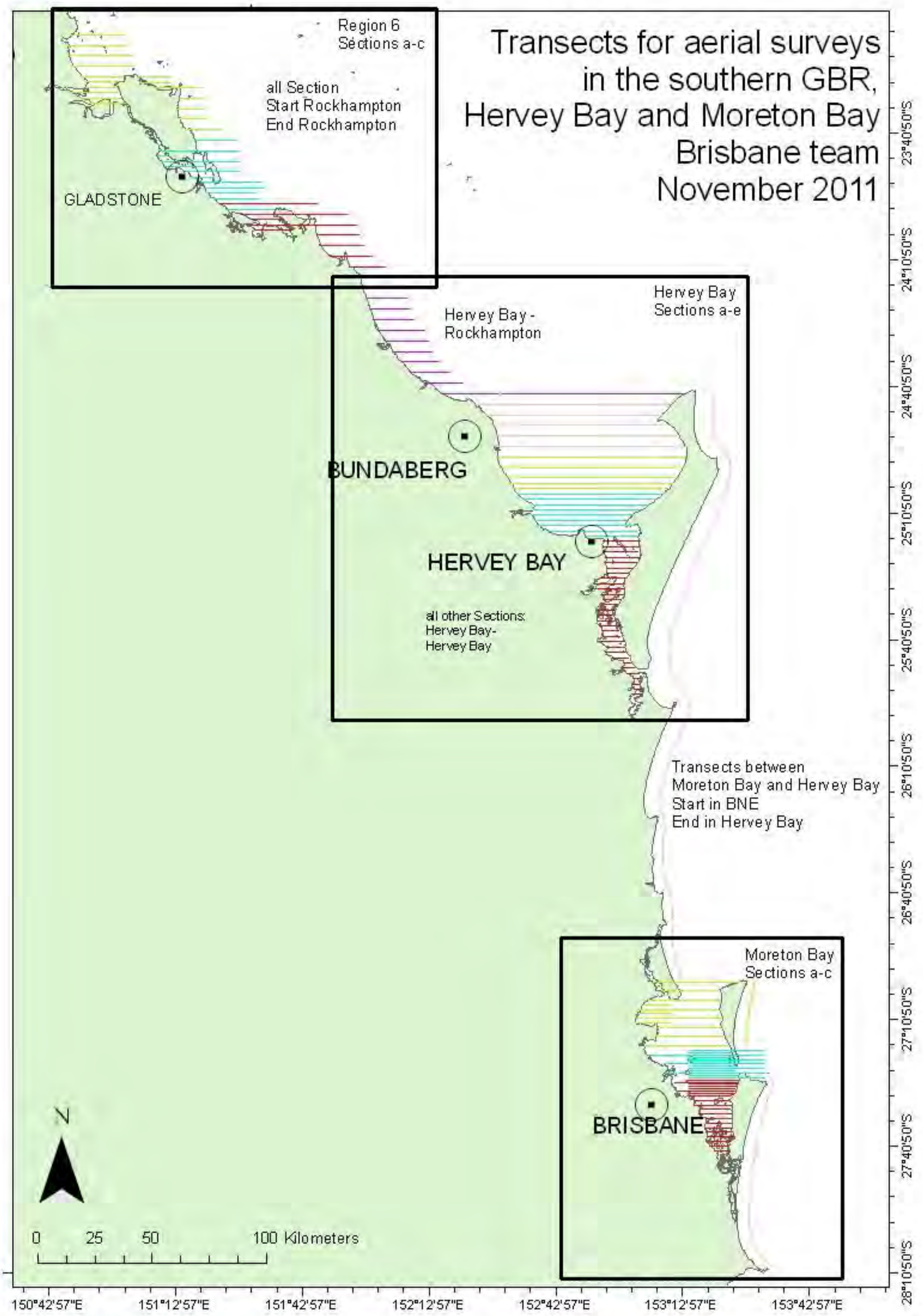

Figure 2: Map showing the east coast of Queensland with transects flow in the November 2011 survey from Rockhampton south. Black boxes mark individual survey regions (Southern Great Barrier Reef region 6, Hervey Bay and Moreton Bay regions).

2.6 Spatial Modelling

We used a modified version of the technique outlined in Grech and Marsh (2007) and Grech *et al*. (2011) to develop spatially explicit models of dugong distribution and relative abundance in the Southern GBR, Hervey Bay and Moreton Bay Regions. We did not integrate the 2011 sightings with aerial survey data from previous years as the number of dugong sightings in the Southern GBR was too small. Instead, we used the uncorrected data on dugong distribution and abundance to develop spatially explicit dugong population models for 2011 only. We also developed models of dugong distribution and relative abundance with the previous survey year (2005) to assess broad scale patterns of movement over time.

We estimated dugong distribution and relative abundance at a dugong planning unit of cell size 2 km * 2 km for the 2005 and 2011 models. Based on the relative density of dugongs estimated from the spatially explicit dugong population models and a frequency analysis, we classified each dugong planning unit as very high (> 0.5 dugongs/km^2), high (0.5 – 0.25 dugongs/km^2), medium (0 – 0.25 dugongs/km^2) and low (0 dugongs/km^2) dugong density (Grech and Marsh 2007; Grech *et al*. 2011).

We used the models of dugong distribution and relative abundance for 2011 and 2005 to estimate the proportion of dugong planning units in 'protected' (Conservation, Buffer, Marine National Park, Scientific Research and Preservation) zones in the Great Barrier Reef and Moreton Bay Marine Parks.[1]

3.0 RESULTS

3.1 Sampling intensity and survey conditions

Sampling intensities were generally high and varied for individual transects between 6.33-37.55% (Appendix Table 1). The survey weather conditions were good and comparable with previous surveys (Appendix Tables 2 and 3). The Southern Team initially encountered favourable weather conditions and was able to conduct multiple flights per day in the Moreton Bay and Hervey Bay Regions. Wind and in particular rain conditions in the north impeded the work of the Northern Team, resulting in delays and weather-related down days. Nonetheless, the entire survey was completed on schedule since such delays were anticipated in the timeframe of the survey.

3.2 Dugong sightings

Maps with the locations and group sizes of all dugong sightings are in the Appendix (Appendix Figures 1-10). A total of 279 dugong groups were sighted for the entire survey (Table 2 and Appendix Table 4). The mean group size differed significantly between the three regions (Kruskal Wallis test, χ^2=5.99, df=2, p=0.05) with 1.40 dugongs (SE = 0.13) for Moreton Bay, 1.50 dugongs (SE = 0.10) for Hervey Bay and 1.25 (SE = 0.11) for southern GBR (all means excluding large herds).

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[1] The Great Sandy Strait Marine Park shapefile has not been released to the public and so was not available to us

We encountered a total of four herds (≥ 10 animals), three in Moreton Bay (44, 117 and 170 dugongs) and one in Hervey Bay (25 dugongs).

Table 2: Number of dugong and calf sightings and group sizes for the three regions surveyed in November 2011. All figures are excluding herds of >10 dugongs.

Region	Number of dugong sightings	Number of dugongs	Number of calf sightings	% calves[3]	Group size Mode	Mean	Range
Moreton Bay[1]	67	94	8	8 (8.5%)	1	1.4	1-7
Hervey Bay[2]	94	124	11	12 (9.7%)	1	1.52	1-6
Southern GBR	53	66	0	0	1	1.25	1-6

[1] total of three herds were sighted (44, 117 and 170 dugongs)
[2] total of one herd was sighted (25 dugongs)
[3]claves as percentage of total number of dugongs sighted.

3.3 Dugong sightings with respect to bathymetry

Dugongs were sighted in waters up to 34 m deep (not corrected for tides). Over the entire survey area, 95% of dugong sightings were in waters less than 20 m deep (81% in waters less than 15m deep; 69% in waters less than 10 m deep). In four areas with high dugong density: Moreton Bay (Moreton Bay Region, blocks 1-6); Hervey Bay (Hervey Bay Region, blocks 1-5); Shoalwater Bay (Southern GBR Region, block S5) and around Hinchinbrook Island (Southern GBR Region, block C10), dugong sightings varied between different depth categories (Figure 3).

For statistical analyses, sightings were grouped in broad depth classes (e.g. <5 m and >5 m) to avoid small sample sizes. In Moreton Bay, Hervey Bay and Shoalwater Bay, dugong distribution varied significantly between depth classes and years (Appendix Figure 11). In Moreton Bay, the total number of dugongs seen varied considerably between years (χ^2=98.38, df=3, p<0.001) with more animals (%) seen in waters deeper than 5 m in 2005 and 2011 than in 2000 and 2001 (Figure 3). In Hervey Bay, a higher percentage of dugongs was seen in waters deeper than 15 m than in previous years (χ^2=61.25, df=6, p<0.001; Figure 3). In Shoalwater Bay, dugongs were significantly more concentrated in water 0-5 m deep in 2011 than in any other year (χ^2=16.72, df=2, p<0.001, Appendix Figure 11). The Hinchinbrook Island area was the only tested area where no significant differences between different depth classes between years was detected (χ^2=7.61, df=4, p=0.11, Appendix Figure 11). However, as a result of the small sample sizes sightings in water deeper than 10 m were grouped together which masked the fact that 2011 was the only year with dugong sightings in waters 20-25 m (Figure 3).

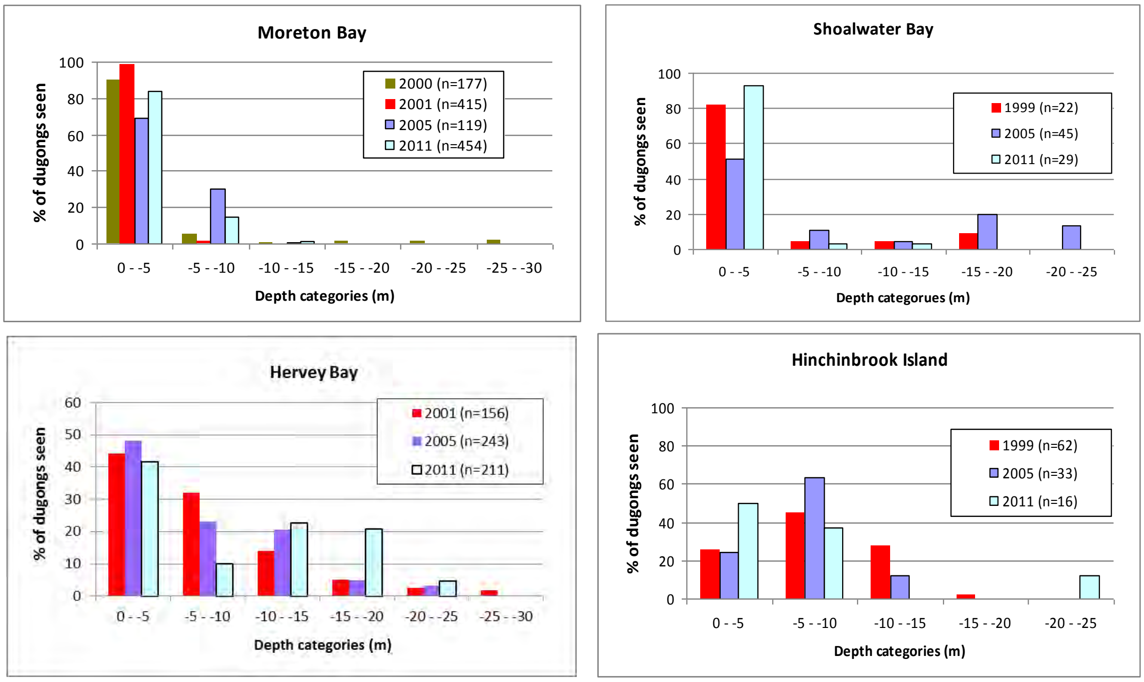

Figure 3: Frequency distribution of dugong sightings with respect to bathymetry for four areas of the November 2011 surveys: Moreton Bay (Moreton Bay Region, blocks 1-6); Hervey Bay (Hervey Bay Region, blocks 1-5); Shoalwater Bay (Southern GBR Region, block S5) and Hinchinbrook Island (Southern GBR Region, block C10). The data indicate that in Hervey Bay and Hinchinbrook Island relatively more dugongs were sighted in deeper water (>15m) in 2011 than in previous surveys.

3.4 Estimates of dugong population size and density

The raw data for sightings of dugong groups for each transect in each block surveyed in November 2011 used to estimate population size are detailed in Appendix Table 4 and Appendix Figures 1-10. Appendix Table 5 provides details of the mean group size estimates and correction factors used to generate the dugong population size estimates in 2011.

Moreton Bay Region

The estimated size of the dugong population in the Moreton Bay Region in November 2011 was 883 $\pm$ 68 using the method of Marsh and Sinclair (1989a). These figures were similar to the population size estimates from 1995 (968 $\pm$ 44, Preen and Marsh 1995), but much higher than the corresponding estimates for 1988 (442 $\pm$ 69, Marsh and Saalfeld 1990a and b) and 2005 (454 $\pm$ 41, Marsh and Lawler 2007) (Figure 4 and Appendix Table 6). Using the Pollock *et al.* (2006) method, population size estimates for 2011 were 700 $\pm$ 156 (Table 4), which was higher than the corresponding estimate for 2005 (421 $\pm$ 60, Marsh and Lawler, 2007).

We found that using the densities generated using the Marsh and Sinclair (1989a) method the dugong density in 2011 differed significantly between blocks but there was no difference among survey years (Table 3, Figure 7). There was a significant effect of interaction between blocks and survey years ($F_{6,75}$ = 2.60, $p < 0.05$) as illustrated in Figure 7. The larger variance component of the among-transect within-block variation among years (0.87) compared with the block variance component (0.17) indicated substantial movements of dugongs among transects within the same block over time. Unplanned comparisons showed that dugong density was significantly lower in Block 3 than Block 4, but there was no difference between Block 3 and Block 6 and Block 4 and Block 6.

Comparison of the results from 2005 and 2011 showed no effect of year for the dugong densities generated using the methodology of Pollock *et al*. (2006): ($F_{1,25}$ =1.24, p = 0.28).

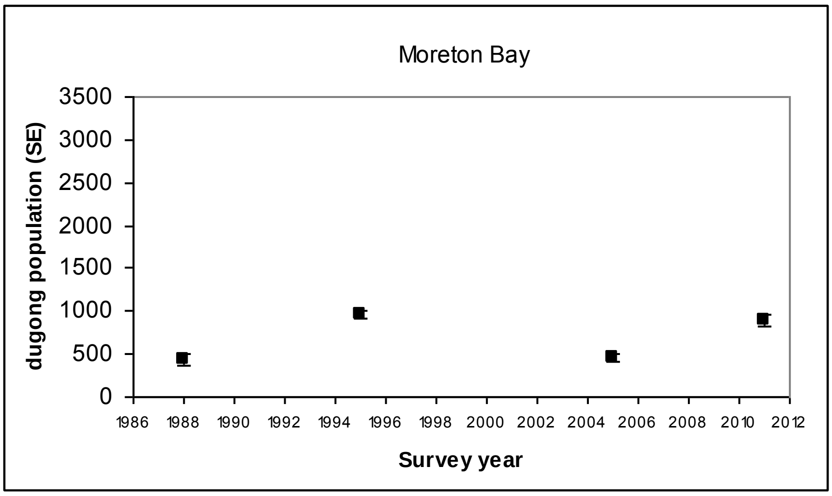

Figure 4: Graph showing the time series of population size estimates (+ SE) obtained from standardised aerial surveys in Moreton Bay (for locations of blocks see Appendix Figure 1). Estimates were obtained using the methodology of Marsh and Sinclair (1989a). Historical data from Marsh and Saalfeld (1990a and b); Preen and Marsh (1995); Marsh and Lawler (2001) and Marsh and Lawler (2007). Note the standard errors are artificially small because the sizes of the large herds have been reported as total counts.

Table 3: Results of A) linear mixed-effects model comparing dugong density produced by Marsh and Sinclair (1989a) across the time series, and B) split-plot design comparing the dugong density using data generated by Pollock *et al*. (2006) for the 2005 and 2011 surveys only.

	Source of variation	Num. DF	Denom. DF	F	MCMC p-value	Variance component
A) Marsh & Sinclair (1989a)	**Moreton Bay 2000, 2001, 2005 and 2011**					
	Block	2	25	12.91	<0.01	
	Among transect within block					0.17
	Year	3	75	0.13	0.92	
	Block x Year	6	75	2.60	<0.05	
	Residual (among transect within block variation among years)					0.87
	Hervey Bay 1994, 1999, 2001, 2005 and 2011					
	Block	3	53	12.12	0.17	
	Among transect within block					0.16
	Year	4	212	2.88	0.08	
	Block x Year	12	212	0.54	0.91	
	Residual (among transect within block variation among years)					1.29
	Southern GBR 1986, 1992, 1994, 1999, 2005 and 2011					
	Block	3	33	1.86	0.23	
	Among transects within block					0.25
	Year	5	165	4.58	<0.05	
	Block x Year	15	165	2.07	<0.05	
	Residual (among transect within block variation among years)					1.34
	Source of variation	**Num. DF**	**Denom. DF**	**F**	**p-value**	
B) Pollock *et al*. (2006)	**Moreton Bay 2005 and 2011**					
	Block	2	25	2.79	0.08	
	Year	1	25	1.24	0.28	
	Block x Year	2	25	1.41	0.26	
	Hervey Bay 2005 and 2011					
	Block	3	53	4.85	<0.05	
	Year	1	53	0.51	0.65	
	Block x Year	3	53	0.49	0.69	
	Southern GBR 2005 and 2011					
	Block	3	34	1.23	0.31	
	Year	1	34	18.1	<0.001	
	Block x Year	3	34	1.74	0.18	

Hervey Bay Region

The estimated size of the dugong population in the Hervey Bay Region in November 2011 was 2116 $\pm$ 108 using the method of Marsh and Sinclair (1989a), and 2029 $\pm$ 576 using the Pollock *et al*. (2006) method. These estimates are somewhat lower than population estimates obtained during the 2005 survey (2547 $\pm$ 410 for Marsh and Sinclair (1989a) and 2077 $\pm$ 543 for Pollock *et al*. (2006), see Figure 5 and Appendix Table 6) but significantly higher than the estimates obtained after the loss of 1000 km^2 of seagrass habitat in 1992 (Preen and Marsh 1995).

The effect of block, year and their interaction did not affect the dugong density significantly, although probability of difference between years was relatively small (p=0.08, Table 3, Figure 7). The large random variance component from the among-transect within-block variation among years (1.29) compared to the block variance (0.16) indicates substantial movements of dugongs within blocks across survey years in this region as well.

Analysis of the data from 2005 and 2011 generated using the Pollock *et al*. (2006) methodology also indicated no significant difference in dugong density between 2005 and 2011 ($F_{1,53} = 0.51$, $p = 0.65$).

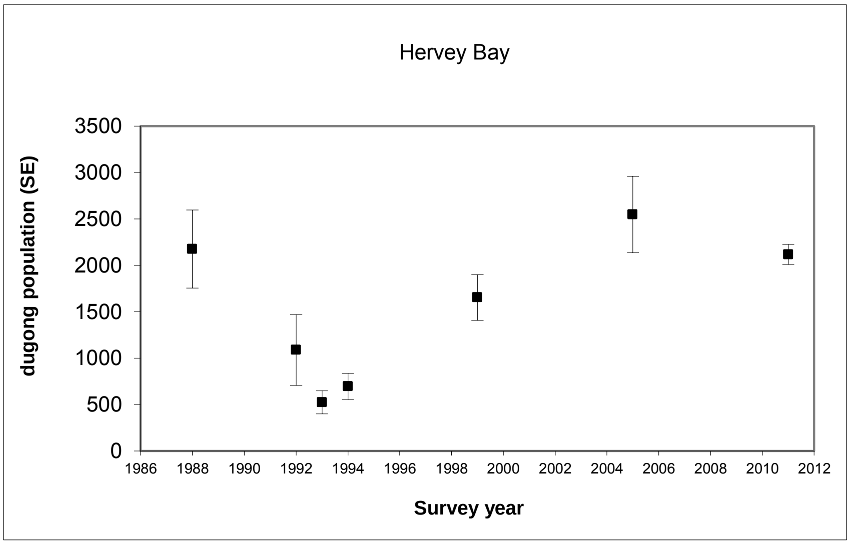

Figure 5: Graph showing the time series of population size estimates (+ SE) obtained from standardised aerial surveys in Hervey Bay (for locations of blocks see Appendix Figure 2). Estimates were obtained using the methodology of Marsh and Sinclair (1989a). Historical data from Marsh and Saalfeld (1990a and b); Preen and Marsh (1995); Marsh and Lawler (2001) and Marsh and Lawler (2007). Note the standard errors are artificially small because the size of the large herds has been represented as total counts. Note the differences between the estimates for 2005 and 2011 using the Pollock *et al*. (2006) methodology are very small.

Southern Great Barrier Reef Region

The estimated size of the dugong population in the Southern GBR Region in November 2011 was 481 $\pm$ 43 using the method of Marsh and Sinclair (1989a), and 608 $\pm$ 213 using the Pollock *et al*. (2006) method. These estimates are the lowest estimates since surveys began in the 1980s (see Appendix Table 7). Only four of the 21 blocks provided sufficient sightings for population size estimations in 2011: S5 (Shoalwater Bay), C6 (Upstart Bay), C10 and C11 (Hinchinbrook area). The dugong population estimates were lower in 2011 than in 2005 for three of these blocks. However, the population estimate for C11 was slightly larger population in 2011 than in 2005 (Figure 6), a result likely caused by the increase in block size in 2011 compared with the 2005 survey as a result of a change in survey design (675 km^2 in 2011 compared with 351 km^2 in 2005).

Dugong density differed significantly among years (Table 3, Figure 7). Difference between blocks was not significant, probably because we limited the analysis to survey blocks with relatively high density of dugongs. There was significant interaction term from blocks and years ($F_{15,16}= 2.07$, $p< 0.05$; see Figure 7). Unplanned comparisons between 2005 and 2011 showed that there was a significant difference in dugong density in Southern GBR

Region; density was significantly lower in 2011 than in any other year. Again, the large variance component of the among-transect within-block variation among years (1.34) compared with the block variance component (0.25) indicated differential distribution of dugongs among transects across survey years.

Comparison between the dugong densities generated using the Pollock *et al.* (2006) methodology for 2005 and 2011 indicated a significant difference in dugong density between years ($F_{1,34} = 18.1$, $p < 0.001$); the density was significantly lower in 2011.

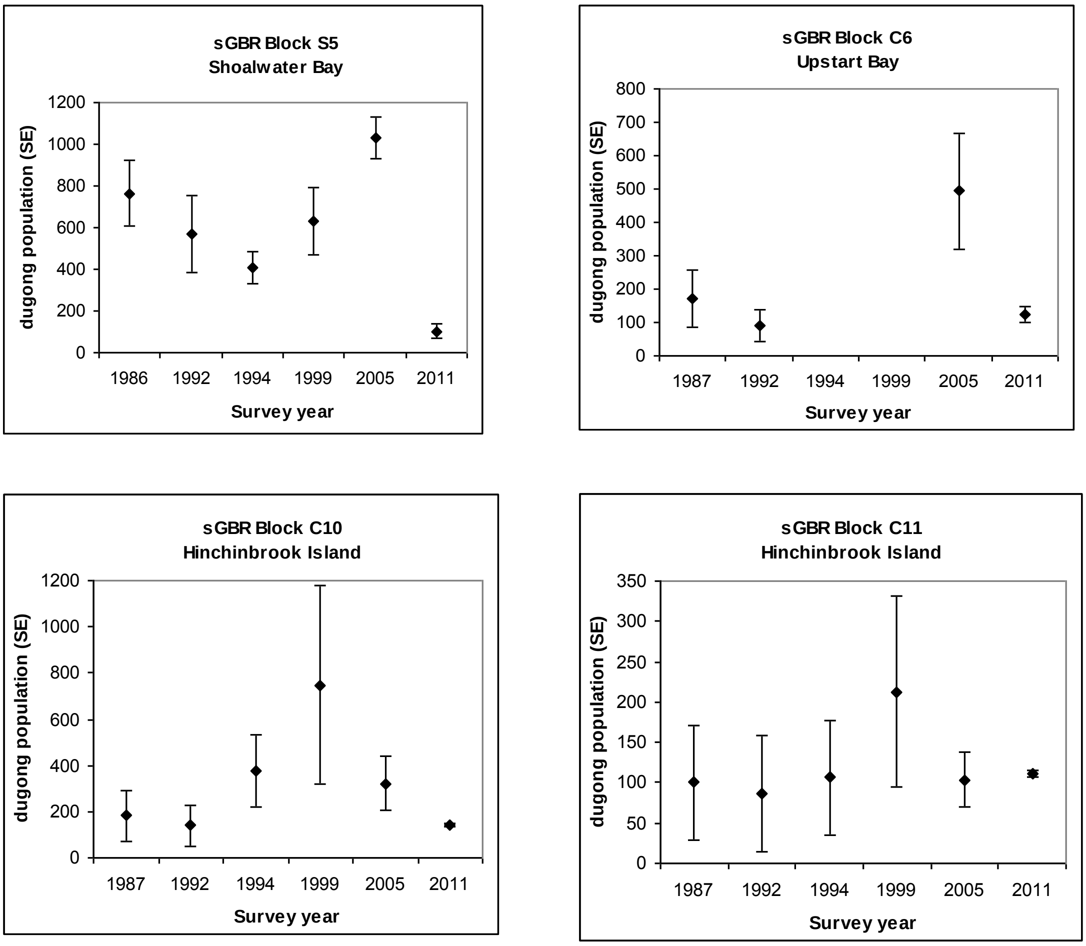

Figure 6: Graphs showing the time series of population size estimates (± SE) obtained from standardised aerial surveys of various parts of the southern Great Barrier Reef Region (for locations of blocks see Appendix Figures 3-10). Estimates were obtained using the methodology Marsh and Sinclair (1989a). Historical data from Marsh and Saalfeld (1990 a and b); Marsh *et al.* (1996); Marsh and Lawler (2001) and (2007). Note different scales of y-axis and uneven arrangement of years on x-axis. For block C6 there were no population estimates available for 1994 and 1999 due to too few sightings. Block C11 covered a larger area in 2011 than in previous surveys (675 km^2 in 2011 compared to 351 km^2 in 2005) which is the likely cause for the apparent slight increase in dugong population size.

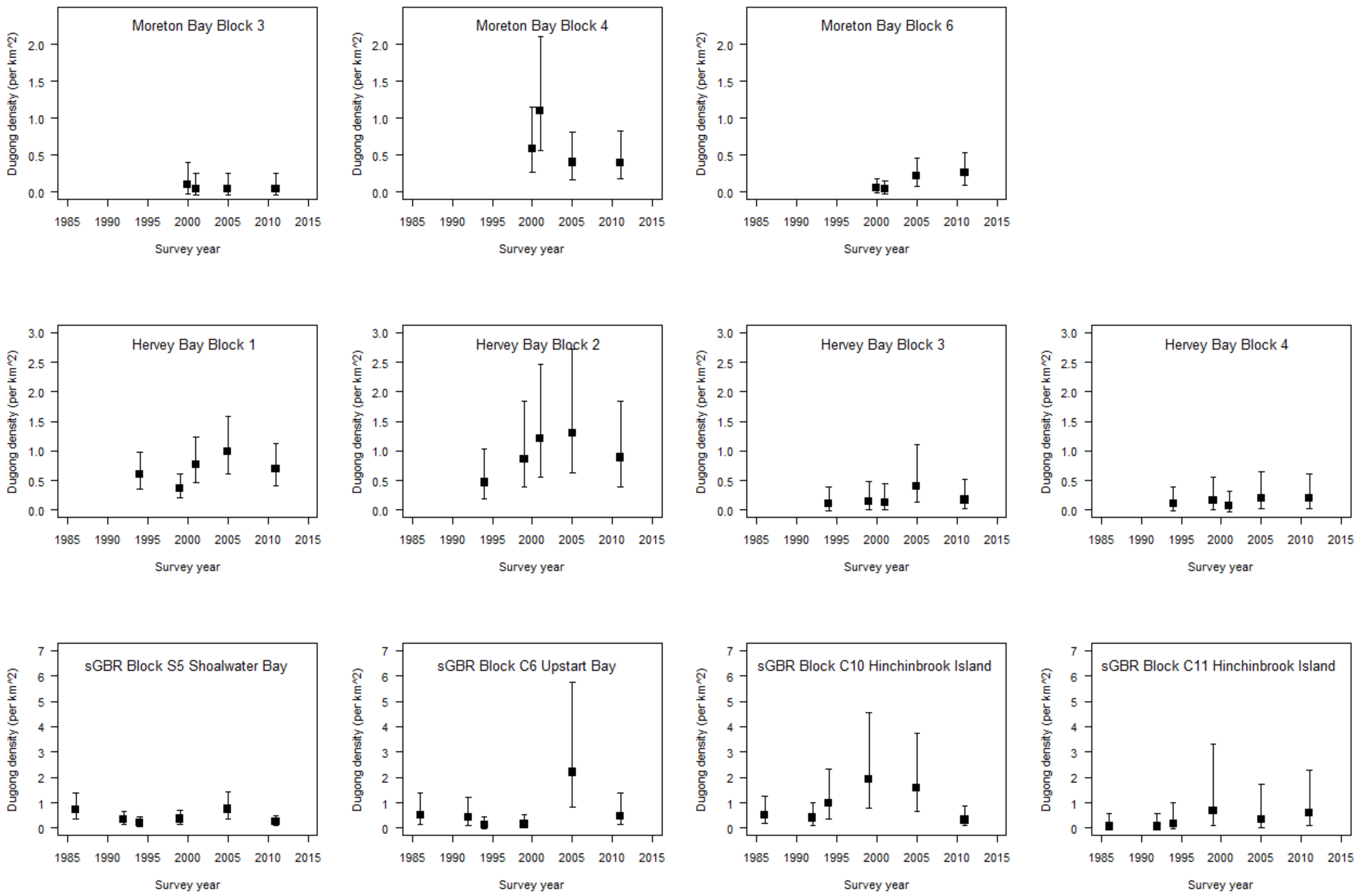

Figure 7: Estimates of dugong density (per km²) in Moreton Bay, Hervey Bay and Southern GBR. The estimates are based on the Marsh and Sinclair (1989a) methodology. Error bars represent 95 % credible intervals for the dugong density.

Comparison between methodologies

Population size estimates for the Moreton Bay and Hervey Bay Regions for 2011 using the Pollock *et al*. (2006) methodology were lower than the corresponding estimates using the older less accurate method of Marsh and Sinclair (1989a) (Table 4). For the Southern GBR Region, the Pollock estimate was above the Marsh and Sinclair estimate (126%). These differences are explained by the heterogeneity in visibility which is averaged out over the entire region in the Marsh and Sinclair method and calculated individually for each sighting in the Pollock method.

Table 4: Comparison of the population size estimates (SE) for dugongs for the Regions of the survey conducted in November 2011 obtained using the Marsh and Sinclair (1989a) and Pollock *et al*. (2006) methods.

	Marsh and Sinclair (1989a)		Pollock *et al*. (2006)		Pollock estimate as % of Marsh and Sinclair estimate
Block	Pop Est	(SE)	Pop Est	(SE)	
			Moreton Bay Region		
4	741	(59)	569	(141)	
6	142	(33)	131	(66)	
TOTAL	883	(68)	700	(156)	79.3
			Hervey Bay Region		
1	585	(93)	397	(152)	
2	1251	(54)	1363	(536)	
3	152	(5)	148	(90)	
4	128	(6)	121	(116)	
TOTAL	2116	(108)	2029	(576)	95.9
			Southern GBR Region		
C6	124	(23)	80	(68)	
C10	144	(8)	168	(132)	
C11	112	(4)	106	(88)	
S5	101	(35)	254	(124)	
TOTAL	481	(43)	608	(213)	126.4

Using the Marsh and Sinclair (1989a) method, dugong density was highest in block MB4 (followed by HB1 and HB2) (Figure 7). Results from the Pollock *et al*. (2006) method show that blocks HB1 and HB2 had the highest dugong density, followed by block MB4. This difference in methodologies is most likely caused by block MB4 having the lowest Beaufort Sea state and turbidity records of all the blocks, hence the mean Availability Probability used for the Pollock *et al*. (2006) method was much higher for block MB4 than for other blocks (0.9 for MB4 while other blocks were around 0.5).

3.7 Spatial Modelling

The 2011 spatially-explicit models of dugong distribution and relative density of the Southern GBR reflect the low number of animals observed during the aerial survey (Figures 8B and 9B) and the 2011 distribution patterns of coastal seagrass habitats (McKenzie *et al*. 2012). There were only two sites in the Southern GBR where dugong relative density was estimated to be very high: Upstart Bay and Shoalwater Bay (Figures 8 and 9). In the previous survey year (2005), regions of very high density included Missionary Bay (north of Hinchinbrook Island), Cleveland Bay and Upstart Bay (Figure 8A) and Shoalwater Bay, Port Clinton and the waters north west of Curtis Island (Figure 9A). The movement of very high density areas from the central to western edge of Shoalwater Bay between 2005 and 2011 is most likely the result of the dugongs responding to tidal movements at the time of survey rather than changes in seagrass distribution. We did not estimate dugong distribution and relative density for the regions between bays as the number of sightings in those regions were too low.

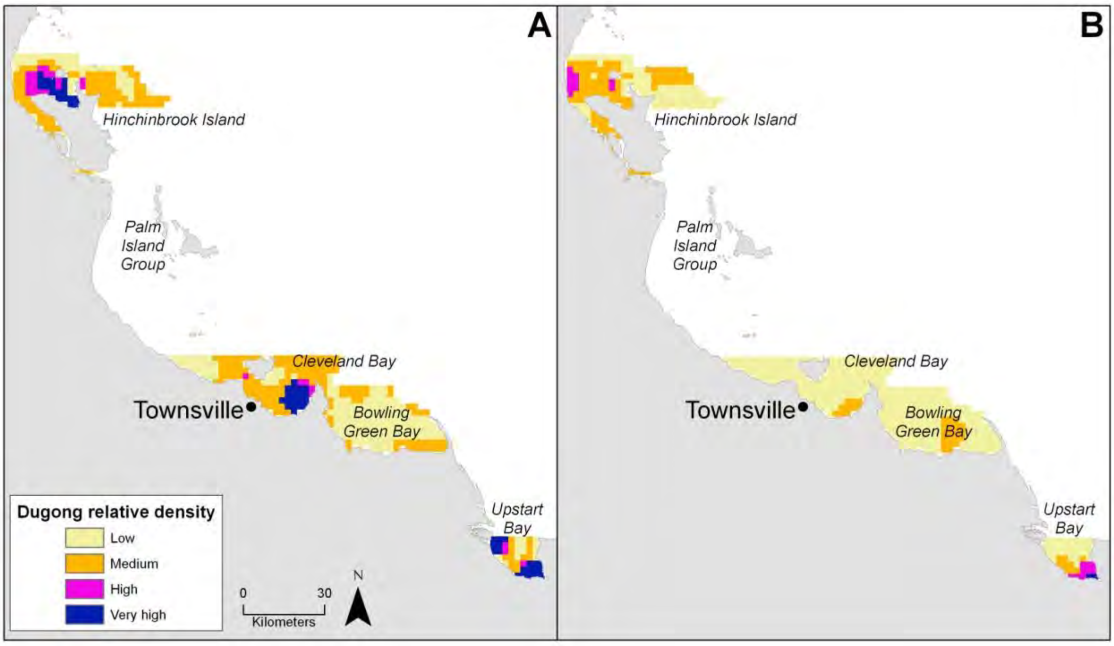

Figure 8: Dugong distribution and relative density Hinchinbrook Island - Upstart Bay (Southern GBR) modelled from aerial survey data in (A) 2005 and (B) 2011.

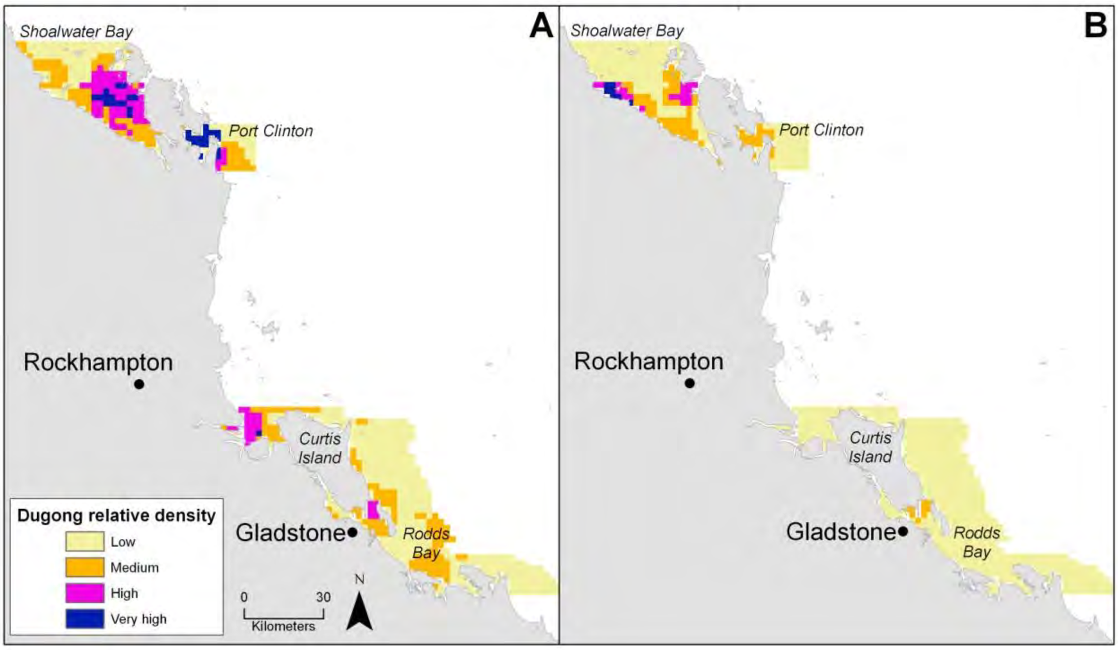

Figure 9: Dugong distribution and relative density Shoalwater Bay - Rodds Bay modelled from aerial survey data in (A) 2005 and (B) 2011.

The spatially-explicit models revealed changes in the distribution patterns of dugongs between the 2005 and 2011 surveys of Hervey Bay (Figure 10) and Moreton Bay (Figure 11), but only a minor difference in the overall number of planning units of low, medium, high and very high dugong density. The 2011 model of Moreton Bay reflects the changes in seagrass distribution caused by flooding in early 2011 (http://www.health-e-waterways.org/reportcard/2011/subregion/Moreton%20Bay). Seagrass was lost south of Bribie Island in Deception Bay due to deteriorating water quality in the region caused by the northward movement of flood waters.

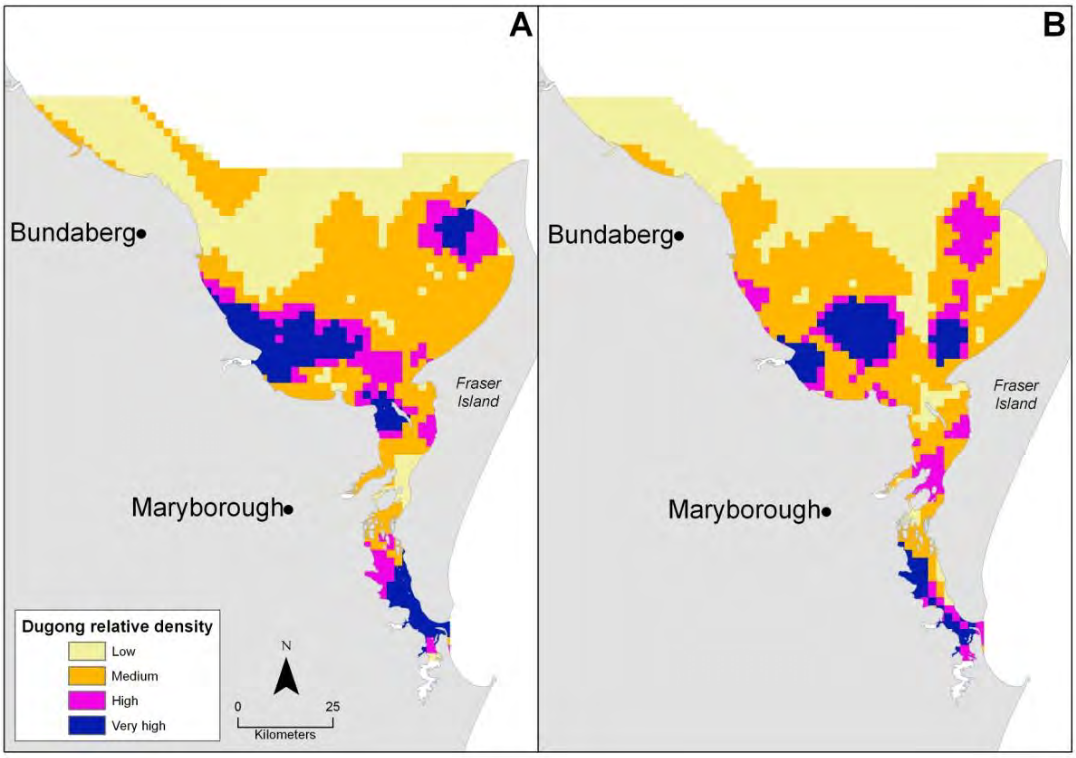

Figure 10: Dugong distribution and relative density Hervey Bay modelled from aerial survey data in (A) 2005 and (B) 2011.

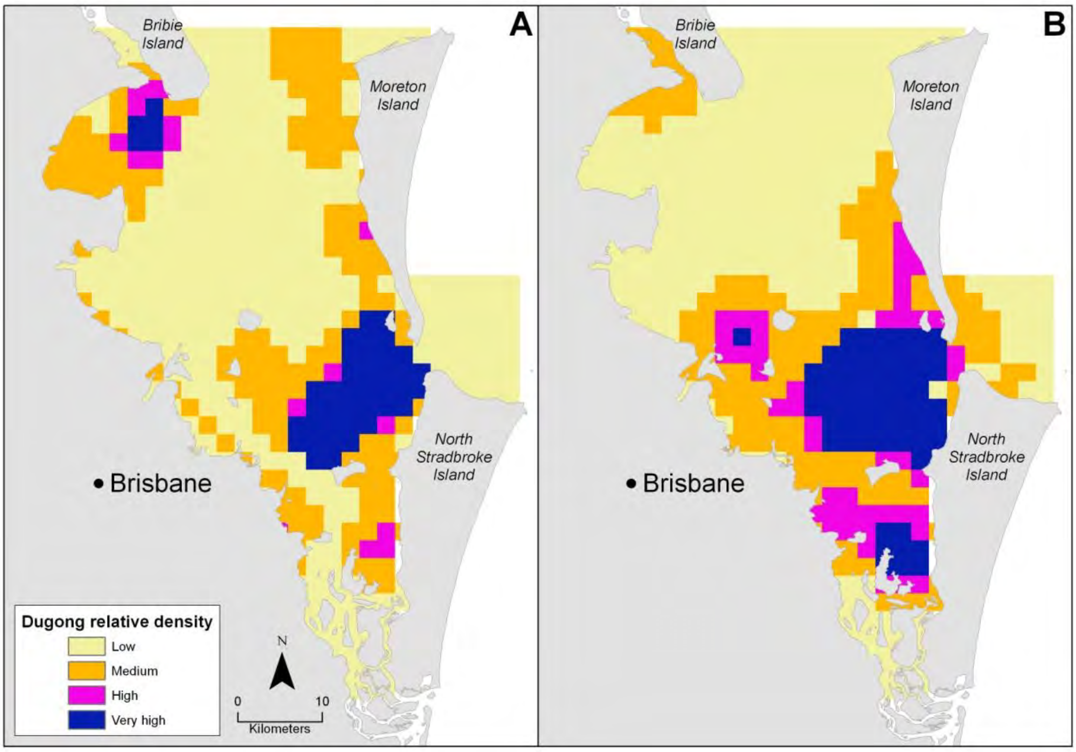

Figure 11: Dugong distribution and relative density Moreton Bay modelled from aerial survey data in (A) 2005 and (B) 2011.

There was only a minor change between survey years in the overall proportion of dugong planning units within 'protected' and 'unprotected' zones of the Great Barrier Reef and Moreton Bay Marine Parks (Table 5). The shape files of the Great Sandy Marine Park were not available so we could not make similar quantitative comparisons for the Hervey Bay region.

Table 5: Proportion (%) of 2005 and 2011 dugong planning units within 'protected' (Conservation, Buffer, Marine National Park, Scientific Research and Preservation) and 'not protected' (General Use and Habitat Protection) zones in the Great Barrier Reef and Moreton Bay Marine Parks.

Dugong relative density	Southern GBR				Moreton Bay			
	2005		2011		2005		2011	
	Protected zones	*Not protected zones*	*Protected zones*	*Not protected zones*	*Protected zones*	*Not protected zones*	*Protected zones*	*Not protected zones*
Low	29	71	27	73	21	79	16	84
Medium	26	74	49	51	16	84	29	71
High	74	26	60	40	16	84	24	76
Very high	76	24	80	20	32	68	21	79

4.0 DISCUSSION

The impacts of the summer of extreme weather events in 2010-2011 on dugongs on the urban coast of Queensland spanned the expected range of responses (Marsh *et al*, 2011): movement of animals from affected areas, increased mortality, and reduction in fecundity evidenced by calf counts. Nonetheless, the responses were geographically uneven indicating that the impacts of the extreme weather events on dugongs were much more serious in the Southern GBR than in Hervey Bay or Moreton Bay.

Irrespective of the methodology used, the estimated total number of dugongs in Moreton Bay plus Hervey Bay was very similar to the combined estimates for 2005 (3001± 412 in 2005 compared with 2999± 128 in 2011 using the Marsh and Sinclair (1989a) methodology and 2538 ± 546 in 2005 compared with 2729 ±599 using the Pollock *et al*. (2006) methodology. The dugong population of Moreton Bay in 2011 was the highest aerial survey estimate since 1995 when the population almost certainly included some animals from Hervey Bay as a result of many animals leaving Hervey Bay as a result of the loss of more than 100km^2 of seagrass after two floods and a cyclone over a three week period (Preen and Marsh 1995; Preen *et al.* 1995; Marsh and Lawler 2007; compare Figures 4 and 5). Some animals may also have moved from Hervey Bay to Moreton Bay in 2011, however, such movements cannot be proven.

In contrast, the estimated size of the dugong population in the Southern GBR Region in November 2011 was the lowest since surveys began in 1986: 481 ± 43 using the methodology of Marsh and Sinclair (1989a), and 608 ± 213 using the Pollock *et al*. (2006) methodology. These patterns were confirmed by the analyses of dugong density excluding the large herds; the 2011 dugong densities for Moreton Bay and Hervey Bay were not significantly different from the long-term averages, while the dugong density in the Southern GBR was significantly lower than for previous surveys.

Overall the dugong population of Moreton Bay and Hervey Bay seems to have been largely unaffected by the floods apart from movement of dugongs within these bays largely due to the loss of inshore seagrasses in coastal intertidal areas. There also may have been some movement of dugongs from Hervey Bay to Moreton Bay but this cannot be verified using the methods used in this study. In contrast, it seems likely that large numbers of animals left the inshore waters of the Southern GBR region. The animals north from Townsville presumably moved to the inshore waters off Cape York. Satellite tracking indicates that dugong can make such a trip in a few days (Sheppard *et al*. 2006) and such movement is consistent with the preliminary data on the genetic structure of the east coast dugong population that suggests a marked genetic break between Townsville and Shoalwater Bay (Blair 2012). Coles *et al*. (2012) undertook a low level helicopter trip from Cairns to Thursday Island covering over 850 kilometres of coastline during the low tides of early March 2012. They reported seagrass meadows in excellent condition and marked with abundant dugong feeding trails (Coles *et al*. 2012).

Dugong mortalities recorded by StandNet for 2011 (Table 6) were the highest since the commencement of the publication of the program's annual reports in 1998. When comparing the data from 2008-2011 inclusive, the number of dugong mortalities recorded in 2011 was higher than any other year for all regions except Cairns. Interpreting regional comparisons in StrandNet is difficult because of the huge difference in reporting effort between regions largely due to the distribution of the human population. Percentage comparisons across regions are probably more robust as regional search effort should be relatively consistent between years. The data indicate that Townsville and Gladstone were the dugong mortality 'hotspots' for 2011. The seagrass in the Townsville (Burdekin) region was in poor condition. For example, seagrass cover had been decreasing at the coastal reference sites since 2009 and the decline continued throughout 2010-11 until only a few isolated shoots remained after Tropical Cyclone Yasi impacted the region in February 2011 (McKenzie *et al*. 2012). The situation in Gladstone was caused by the 2011 floods plus the loss of seagrass due to port development.

Table 6: Annual strandings of dugong recorded in StrandNet (Queensland Department of Environment and Research Management

(www.derm.qld.gov.au/wildlife-ecosystems/wildlife/pdfs/marine-strandings-updata-201211.pdf)

Year	2011		2010		2009		2008	
	#	%	#	%	#	%	#	%
Moreton Bay 27°	21	11	17	20	9	15	11	26
Hervey Bay 25°	21	11	9	10	13	21	7	17
Gladstone 23°	12	6	3	3	1	2	4	10
Mackay 21°	4	2	2	2	1	2	3	7
Townsville 19°	54	29	19	22	11	18	5	12
Cairns 16°	13	7	17	20	12	19	1	2
Remainder of Qld	62	33	20	23	15	24	10	24
Total	187[1,2]	100	87	100	62	100	42	100

1. Includes 4 animals released alive
2. Data to December 20 2011

As explained in the introduction, the impact of extreme weather events on dugong calf counts is expected to be lagged by two years (Marsh *et al*. 2011). No calves were seen in the Southern GBR during the 2011 survey. In contrast, the proportion of calves in Hervey Bay (9.7%) and Moreton Bay (8.5%) in 2011 were within the range expected for 'normal conditions' (Grayson *et al*. 2008). These regional differences reflect both the recent history of seagrass condition in the region and the nature of the extreme weather events in 2010-11. The seagrasses in the Southern GBR south to Great Sandy Strait had been in decline for several years before the floods and cyclones of the summer of 2010-

2011 and were considered 'vulnerable' (McKenzie *et al*. 2012) with declining trajectories reported throughout much of the GBR. After the extreme weather events of the summer of 2010-2011, the inshore seagrass meadows of the Southern GBR plus two inshore sites adjacent to Hervey Bay were variously assessed as being in fair to poor condition (McKenzie *et al*. 2012; Table 7). Nearly three-quarters of the monitored sites had declined in abundance over the previous 12 months and 80% showed a declining long-term trend (5-10 years); 55% of sites exhibit a shrinking meadow area, sites have limited to no seed production (essential for rapid recovery); there are indications of light limitation at 90% of sites; nutrient enrichment at 83% of sites and 40% of sites have either high or elevated nitrogen (McKenzie *et al*. 2012). Thus the absence of calves in the southern GBR in 2011 reflected the poor status of the dugong's food supply even before the cyclone.

Table 7: Assessment of the status of the seagrass beds from standard monitoring sites.

REGION	July 2010-May 2011
Wet Tropics [1]	Fair
Burdekin [1]	Poor
Mackay-Whitsunday [1]	Poor
Fitzroy [1]	Fair
Burnett-Mary [1]	Poor
Moreton Bay - Eastern Banks [2]	Excellent -

[1]McKenzie *et al*. (2012)
[2] SEQ-Waterways-Report -Card -2011.pdf

In contrast, the seagrass on the Eastern Banks in Moreton Bay had been in 'Excellent' condition (SEQ-Waterways-Report -Card -2010.pdf) before the January 2011 flood. Even though the water quality in more than half the zones in Moreton Bay remained the same or declined after the flood, the Eastern Banks, which are habitat for most of the dugongs, declined only from Excellent to Excellent Minus due to increased algae and some decrease in water quality with some loss of seagrass. Nonetheless, Lanyon *et al*. (2011) conduct health assessments of dugongs in this region to measure clinical health parameters and levels of pollutants, including heavy metals in Moreton Bay after the floods. Eight months after the floods they found that 17% of the animals they sampled in Moreton Bay were in poor (thin) condition, possibly because of dugongs that had moved onto the banks from the areas of western Moreton Bay which had been impacted by the floods (Figure 11). It will be interesting to see if this decline in nutritional status is reflected in reduced calf counts in Moreton Bay in 2012.

Seagrass meadows appear to have variable recovery potential due to changeable light levels and seed availability both spatially and temporally. Assuming a return to El Niño conditions, estimated recovery times range from less than one season in Shoalwater Bay in the Fitzroy region to more than 5 years in parts of the Wet Tropics. In many areas, the estimated time to recovery to a *pioneer* community of 25% of previous mean cover (*Halophila* dominated) is expected to be 1-2 years (McKenzie *et al*. 2012). Dugongs are returning to areas such as Cleveland Bay near Townsville (personal observation) suggesting that the seagrass is recovering. The StranNet records for 2012 at the time of writing (May 2012) indicate that the number of dugong carcasses being recovered in 2012 is unexceptional. Nonetheless, low fecundity/calf survivorship is expected to persist for several years, highlighting the need to minimise adult mortality to maximise the opportunity for population recovery (Marsh *et al*. 2011).

4.1 Implications for Management

4.1.1 Zoning

There was only a minor change between survey years in the overall proportion of high and very high density dugong planning units within 'protected' and 'unprotected' zones of the Great Barrier Reef Region's marine parks (Table 5). The 'protected' proportions are also relatively high. The mirror zoning of the Queensland coastal marine park and the Great Barrier Reef Marine Park provides co-ordinated protection of dugongs and their coastal habitats in the Great Barrier Reef region.

Nonetheless, the results of both the 2005 and 2011 surveys indicate that a much lower proportion of high and very high density dugong planning units are highly protected in Moreton Bay than in the Southern GBR (Table 5) suggesting a need to reconsider the initiatives to protect dugongs in Moreton Bay, especially given the numbers of dugong carcasses salvaged from this region (Table 6). We could not make similar quantitative comparisons for the Hervey Bay region, however, qualitative comparison of the zoning plan for the Great Sandy Marine Park http://www.derm.qld.gov.au/parks_and_forests/marine_parks/pdf/great-sandy-zoning-new.pdf and Figure 10 indicate that there are large areas of high and very high density dugong habitat that are zoned for General Use. The proportion of unprotected dugong habitat was greater in 2011 than in 2005 because of the movement of dugongs away from the protected intertidal regions that are most adversely affected by floods (Figure 10). Given that the inshore seagrass meadows in Hervey Bay have been severely damaged by flood events on several occasions over the last 20 years (Preen *et al*. 1995, Campbell and McKenzie 2004, Gräwe *et al*. 2010), it would be prudent for the Queensland government to increase the protection of the offshore seagrass beds that are clearly very important dugong habitat, particularly after extreme weather events such as occurred in the summer of 2010-2011.

4.1.2 Emergency powers

There were no acute emergencies involving dugongs associated with the extreme weather events of 2010-11. In contrast, there was a public outcry over the deaths of 22 green turtles that were incidentally caught by commercial net fishers targeting almost 20,000 barramundi that washed over the Awoonga Dam spillway after the floods. The Queensland government imposed a temporary netting ban for two months by issuing an interim conservation order under the Nature Conservation Act 1992. The Queensland Government now proposes to legislate to introduce a provision to allow permanent or temporary 'special management declarations' to prevent or remove threatening processes to populations of marine mammals in the wild. Declarations can be made for number of reasons including protecting significant habitat, protecting animals from continued disturbance and allowing scientific research. The new legislation will strengthen the capacity of the state government to respond to emergencies involving marine mammals including dugongs. The Commonwealth Government also has powers under the provisions in their Zoning Plan (Division 4.2 Special Management Areas) to implement an emergency response should the situation call for it, so it appears that both governments have the statutory powers to deal with emergencies resulting from extreme wether events such as occurred in the summer of 2010-2011.

4.1.3 Regional Management of Fisheries

Although the movements of individual dugongs have not been documented, the extreme weather events of the summer of 2010-2011 almost certainly caused many dugongs to move from their usual habitats as discussed above. Such movements increase the justification for zoning the East Coast Inshore Finfish Fishery. This approach would enable fishing practices to be tailored to individual areas to minimise their interactions with dugongs and to take advantage of local knowledge and increase social cohesion among fishers (McPhee 2012). Regional management in the Burdekin area has resulted in changes aimed at significantly reducing interactions between commercial netters and dugongs. This example shows that regional management can result in industry led changes to net fishing practices that should be of direct benefit for species of conservation concern, especially in the wake of extreme weather events when it is important to minimise the risk of dugong mortality, particularly adult mortality (Marsh *et al*. 2011). The upcoming structural adjustment of the East Coast Inshore Finfish Fishery is an opportunity to move to regional zoning of the fishery. The predicted response of dugongs to the increase in the severity of extreme wether events predicted by climate change is further justification for this approach.

4.1.4 Coordination of Regional Management of Indigenous Hunting

In response to the extreme wether of 2010-11, the Gooreng Gooreng, Gurang, Taribelang Bunda and Bailai peoples voluntarily agreed not to hunt dugongs for five years from 2011 and to limit their take of green turtles to 20 a year. These Indigenous groups from central Queensland imposed the bans after negotiations with the state government. The agreement covers waters from Burrum Heads, south of Bundaberg, to Curtis Island off Gladstone, a distance of several hundred kilometres. Given the importance of minimising dugong mortality in 2011, it would have been ideal if a similar response could have been co-ordinated across Indigenous groups along the entire urban cost of Queensland, highlighting the need for the reestablishment of a regional Indigenous co-ordinating body to co-ordinate the responses of Traditional Owners to extreme weather events in their Sea Country.

4.1.5 Port Development

We appreciate that the issues associated with the recent increased port development along the GBR coast are complex. However, ports pose significant threats to dugongs through the increased risk of mortality from vessel strike, the loss of seagrass habitat through dredging and the fragmentation of the coastal environment. We consider that several well-managed mega-ports would pose substantially fewer risks dugongs than a larger number of smaller ports. A low number of well-managed mega-ports would result in:

- Localisation of the inevitable associated deterioration in the chemical environment and the consequential risks to seagrasses and dugongs;
- Localisation of the inevitable loss of seagrass associated with land reclamation and dredging;
- Reduced risk of dugong habitat fragmentation;
- Reduced risk of vessel strike to dugongs;
- Reduced risk of scope creep: small ports inevitably expand into larger ports.

In addition, the capacity of larger ports to manage their impacts on dugongs is likely to be much greater than that of smaller parts because of the economies of scale.

5.0 CONCLUSIONS

Marsh *et al*. (2011) concluded that along the urban coast of Queensland the dugong qualified for the regional IUCN Listing of Critically Endangered based on the estimated size reduction of >80% over the previous three generations (Marsh *et al*. 2005). The time series of aerial surveys prior to 2011 suggested that the decline has stabilised (Marsh *et al*. 2011) but the situation has certainly deteriorated in the Southern Great Barrier Reef region as a result of the decline in habitat quality at least since 2009 exacerbated by the extreme weather events of 2010-11. The situation in Hervey Bay and Moreton Bay appears much less serious but the risks to dugongs could be improved by increasing protection to the regions of high and very high dugong density in both bays.

If the dugong population is to recover along the urban cost of Queensland, it will be essential to minimise all anthropogenic sources of dugong mortality. As discussed above, we consider that regional zoning of the East Coast Inshore Finfish Fishery and reestablishment of a regional Indigenous co-ordinating group would be significant initiatives. The recent increased risk to dugongs from port development also needs to be addressed as a matter of urgency. It will be very important to maintain the mirror zoning of the Queensland coastal marine park and the Great Barrier Reef Marine Park is maintained to provide co-ordinated protection of dugongs and their coastal habitats in the Great Barrier Reef region.

ACKNOWLEDGEMENTS

The Australian Marine Mammal Centre and NERP Tropical Ecosystem Hub funded this survey. We thank our pilots David St. John, Ryan Low, Michelle Hill, and Joe Raukawa, and observers Charlotte Simsar, Coralie D'Lima, Jodie Haig, Kana Koichi, Karmen Luzar, Kym Collins, Lee Bastin, Milena Kiatoski-Kim, Moanalani Tuipulotu and Veronique Mocellin and ground support staff Andrew Curnock and Alicia Schmidt-Roach. The survey was flown under Permit WISP10147411 from the Queensland Parks and Wildlife Services.

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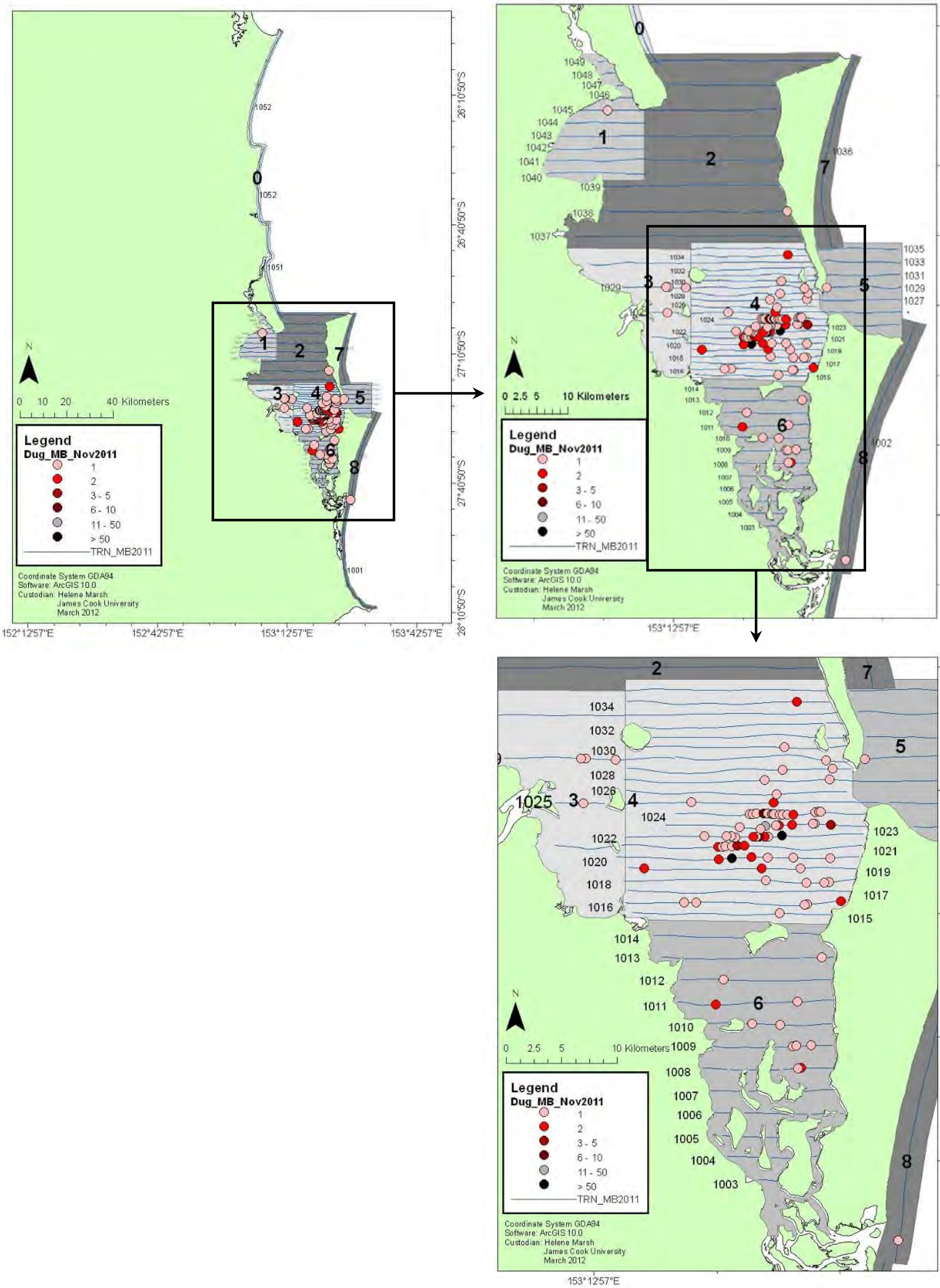
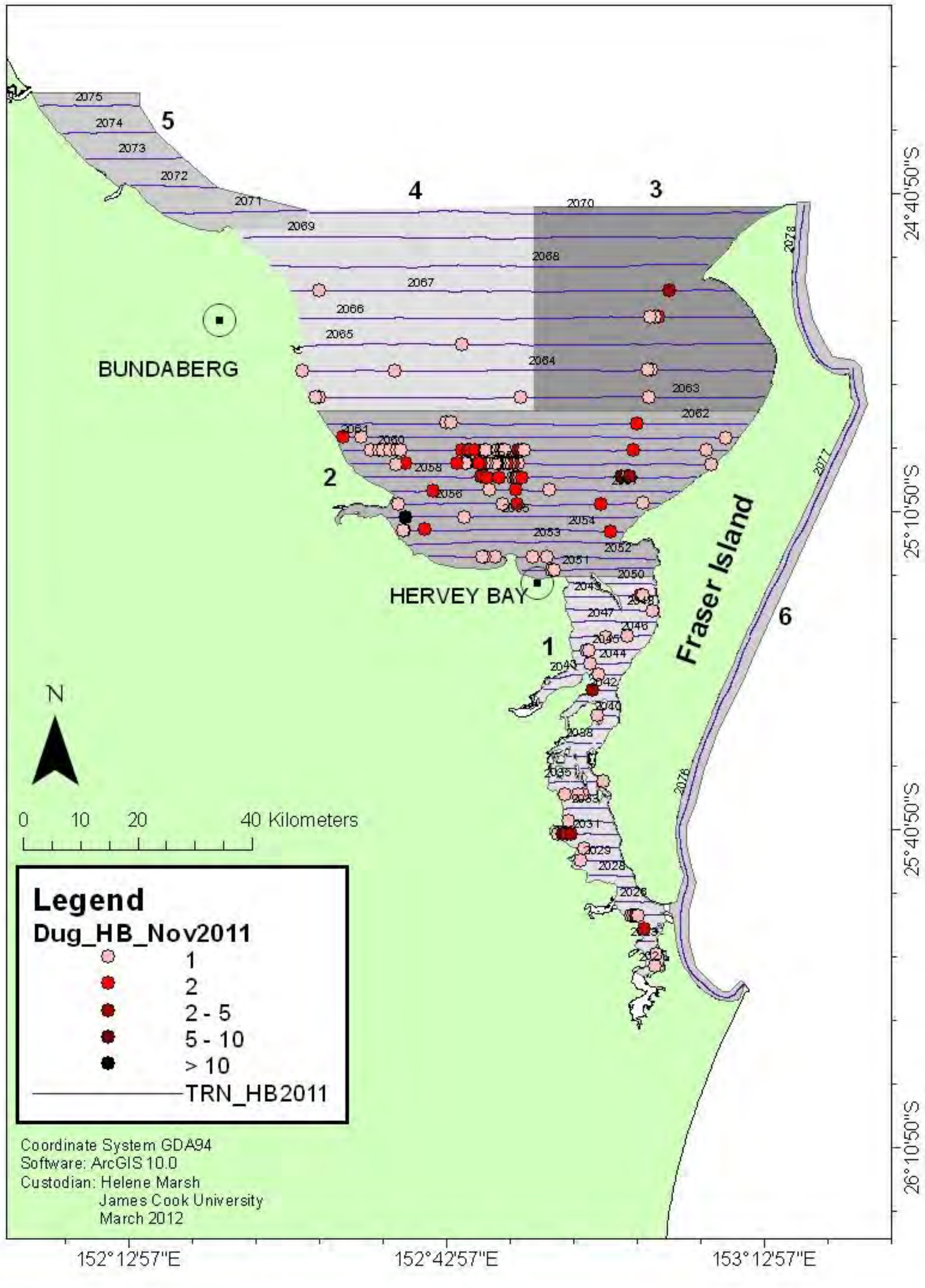
APPENDICES

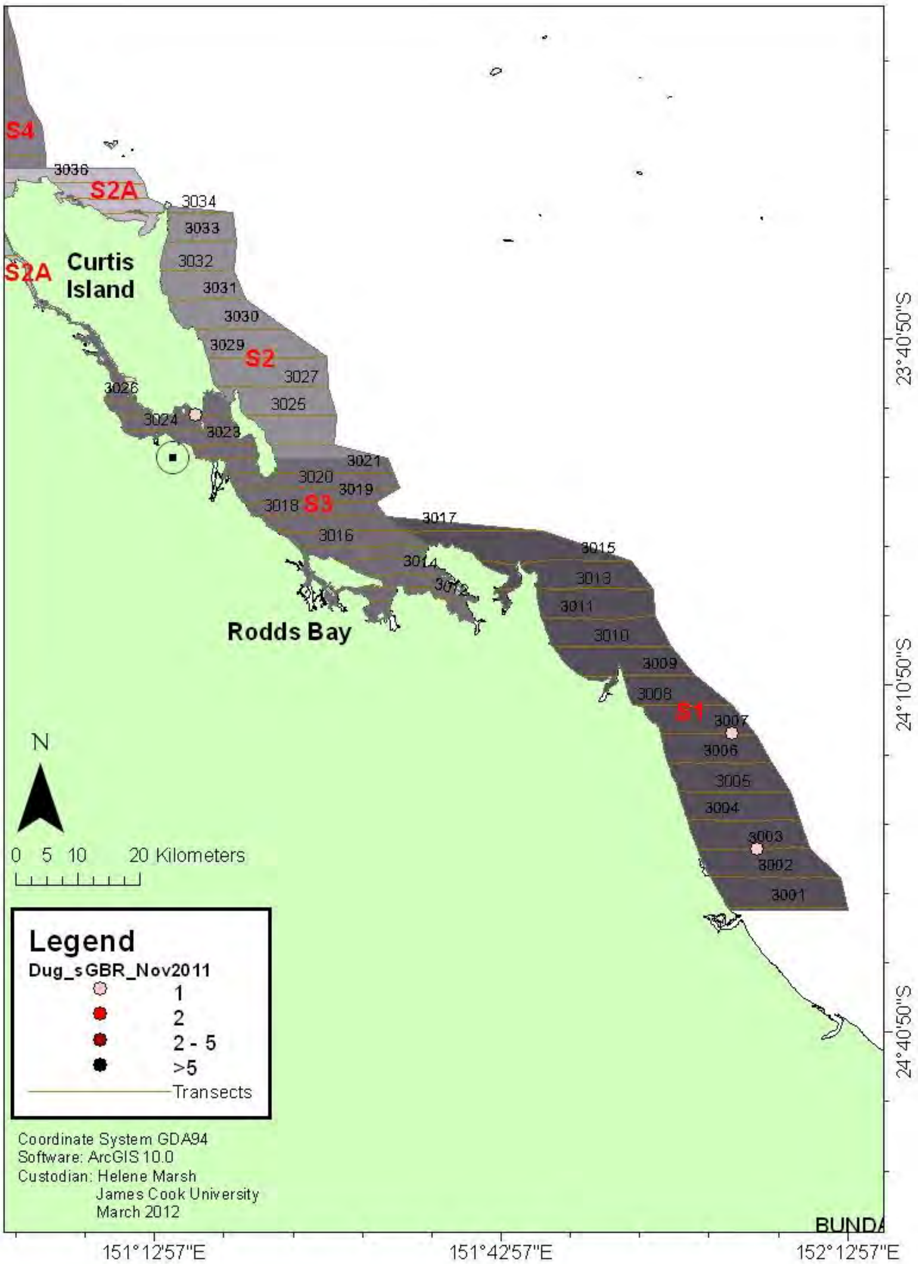
Appendix Figure 1: GPS tracks of transects (four digit numbers) flown in the nine blocks (shaded areas represent blocks 0-8, numbers are in bold) in the Moreton Bay Region in November 2011 and the positions and sizes of the dugong groups sighted.



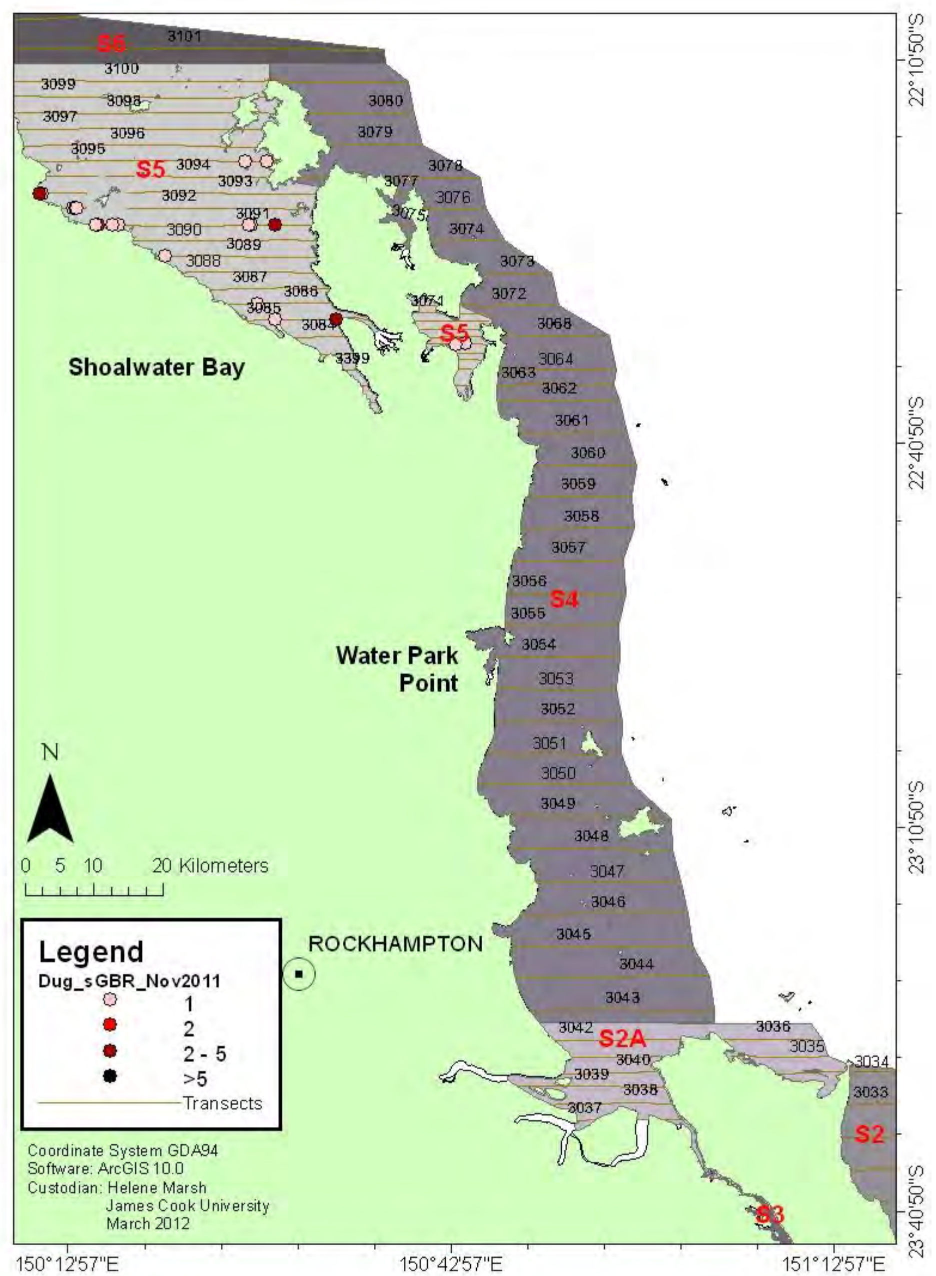
Appendix Figure 2: GPS tracks of transects (four digit numbers) flown in the nine blocks (shaded areas represent blocks 0-8, numbers are in bold) in the Hervey Bay Region in November 2011 and the positions and sizes of the dugong groups sighted.



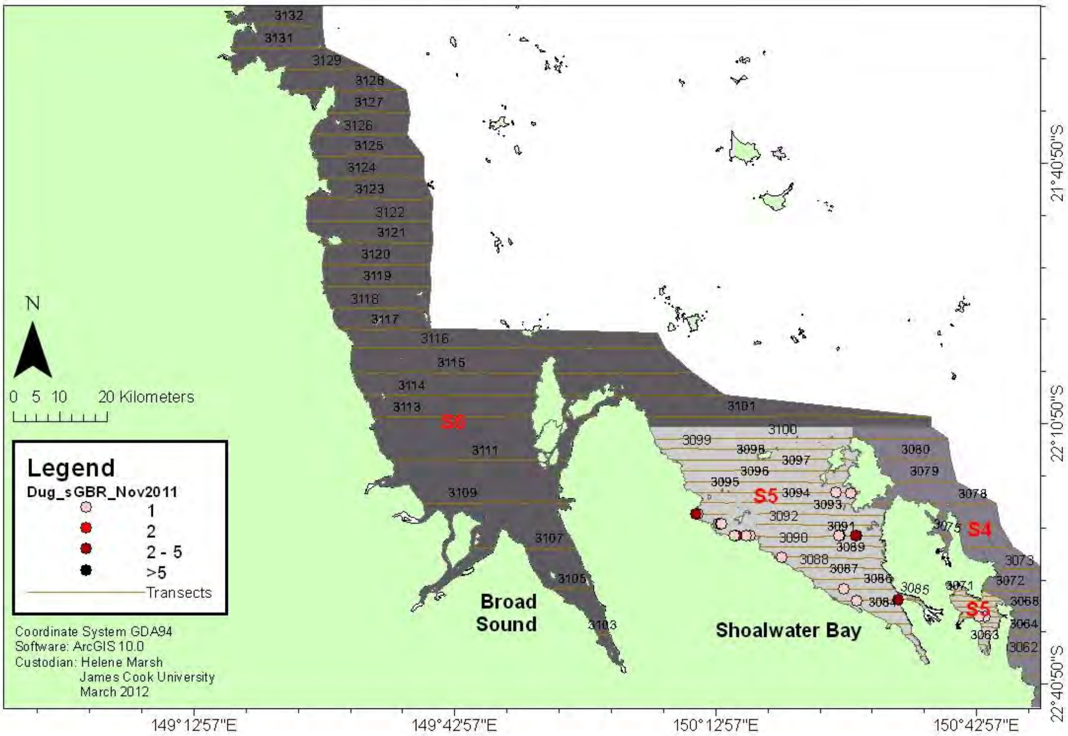
Appendix Figure 3: GPS tracks of transects (four digit numbers) flown in the blocks S1, S2 and S3 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



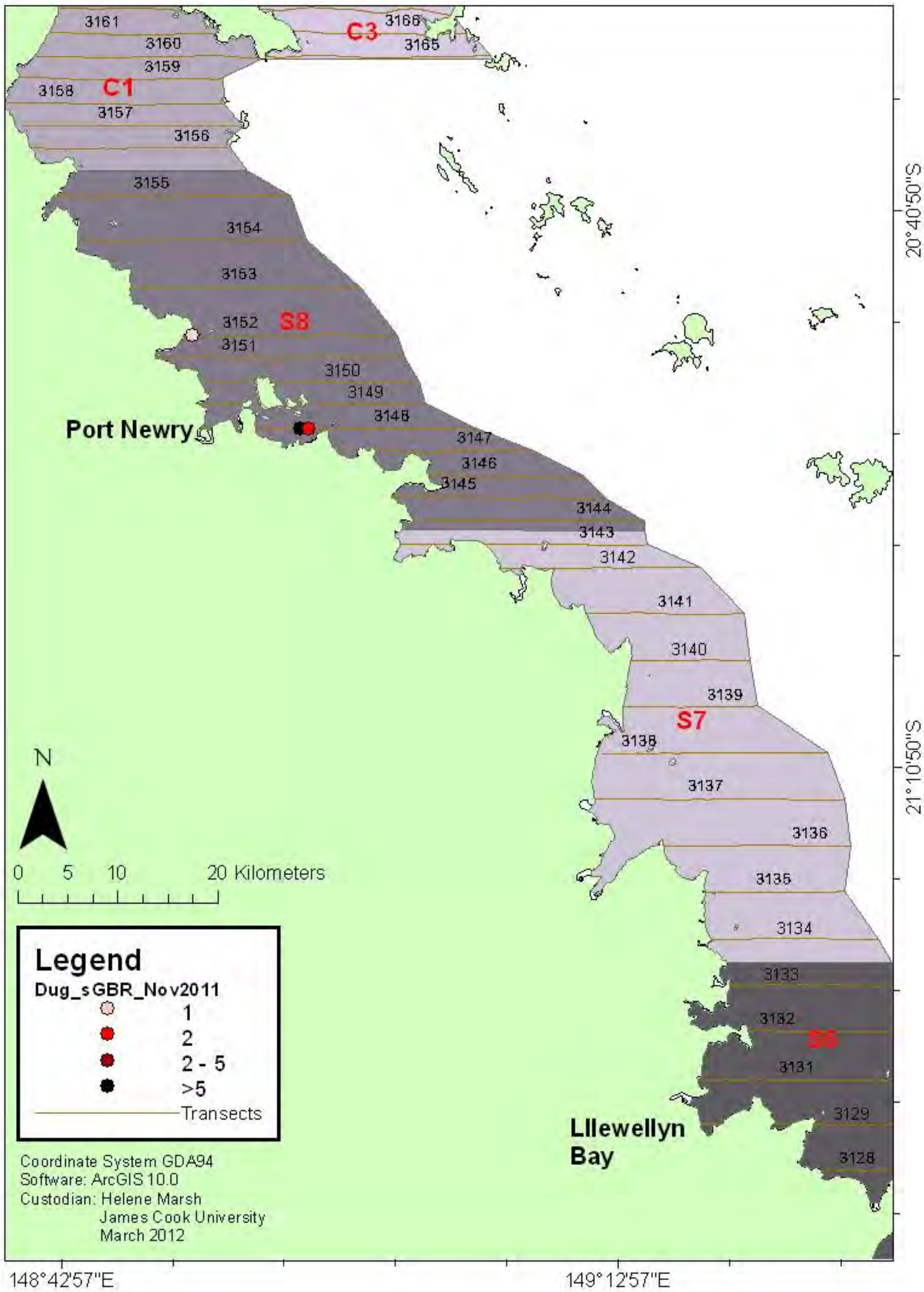
Appendix Figure 4: GPS tracks of transects (four digit numbers) flown in the blocks S2A, S4 and S5 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



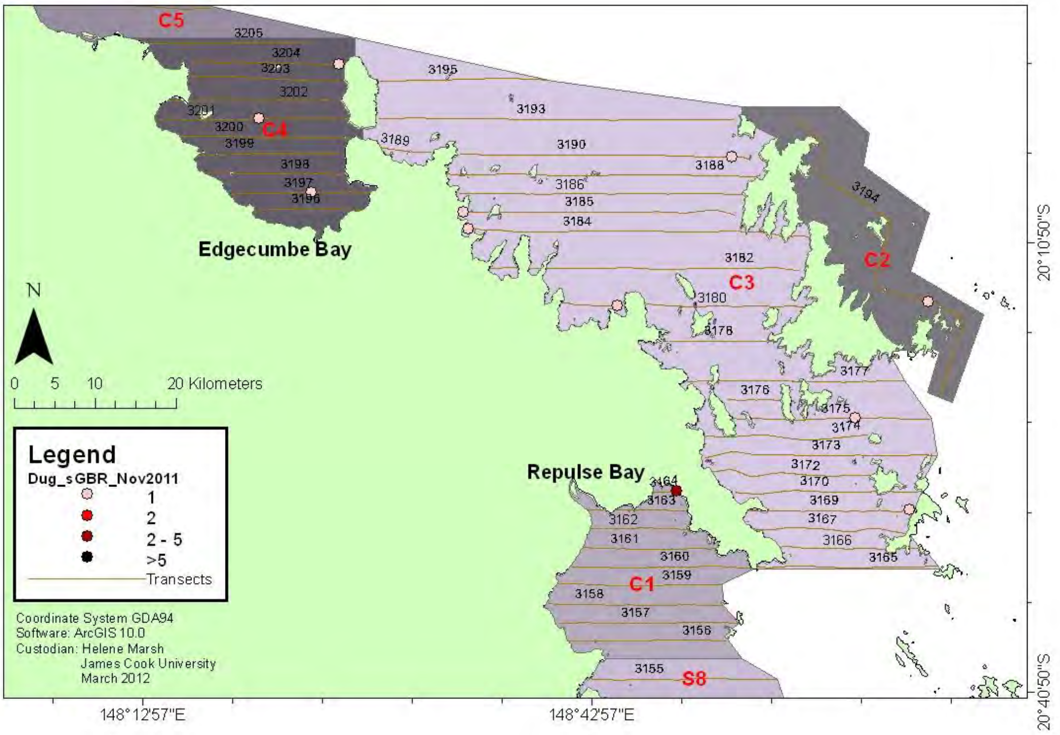
Appendix Figure 5: GPS tracks of transects (four digit numbers) flown in the blocks S5 and S6 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



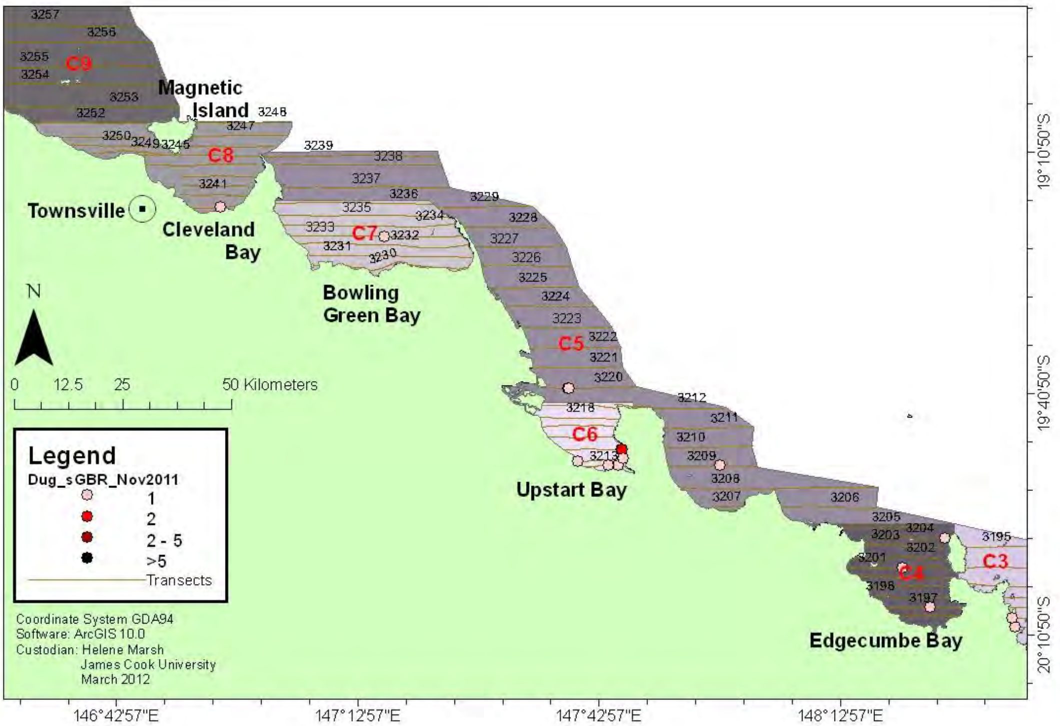
Appendix Figure 6: GPS tracks of transects (four digit numbers) flown in the blocks S7 and S8 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



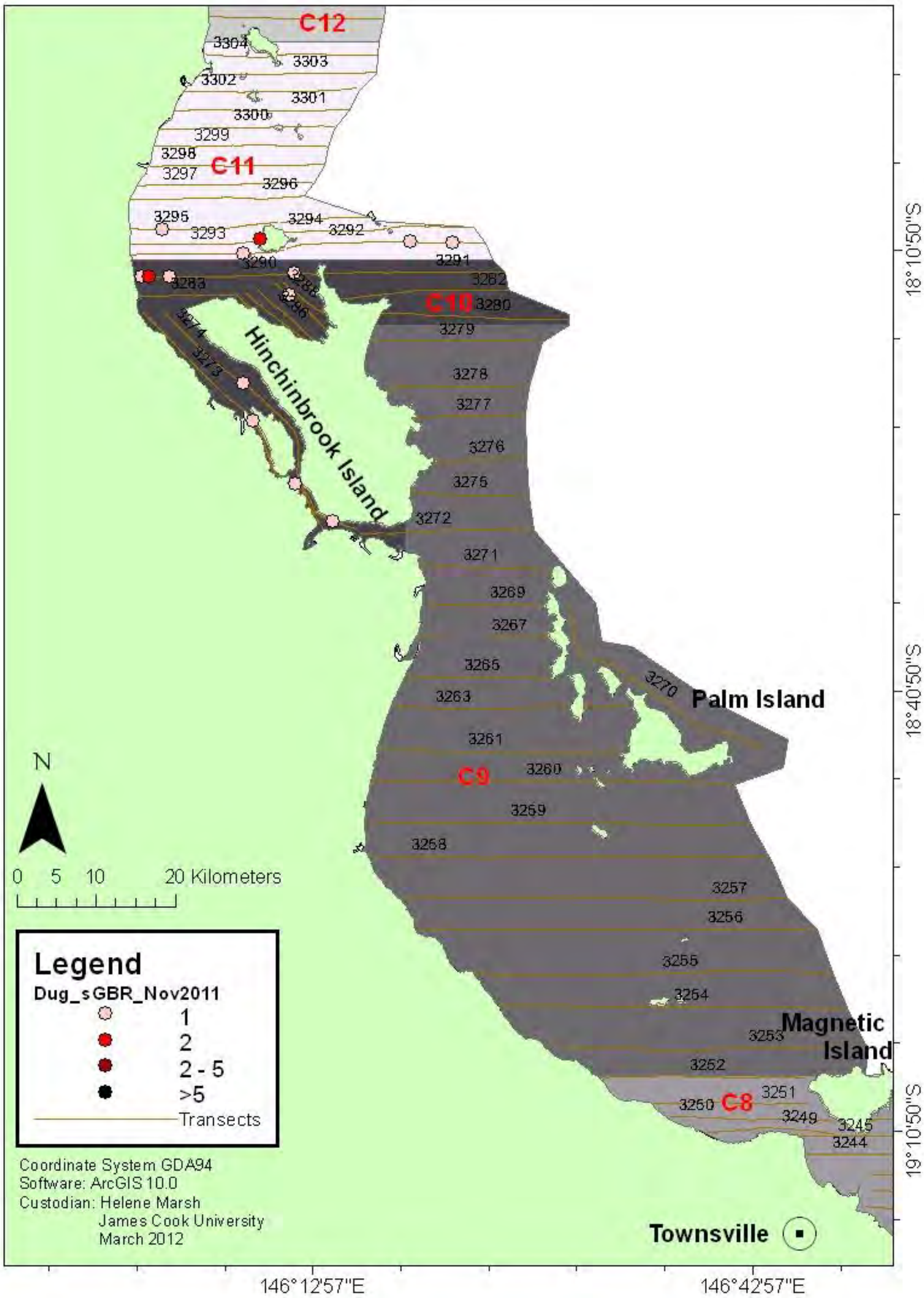
Appendix Figure 7: GPS tracks of transects (four digit numbers) flown in the blocks C1, C2, C3 and C4 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



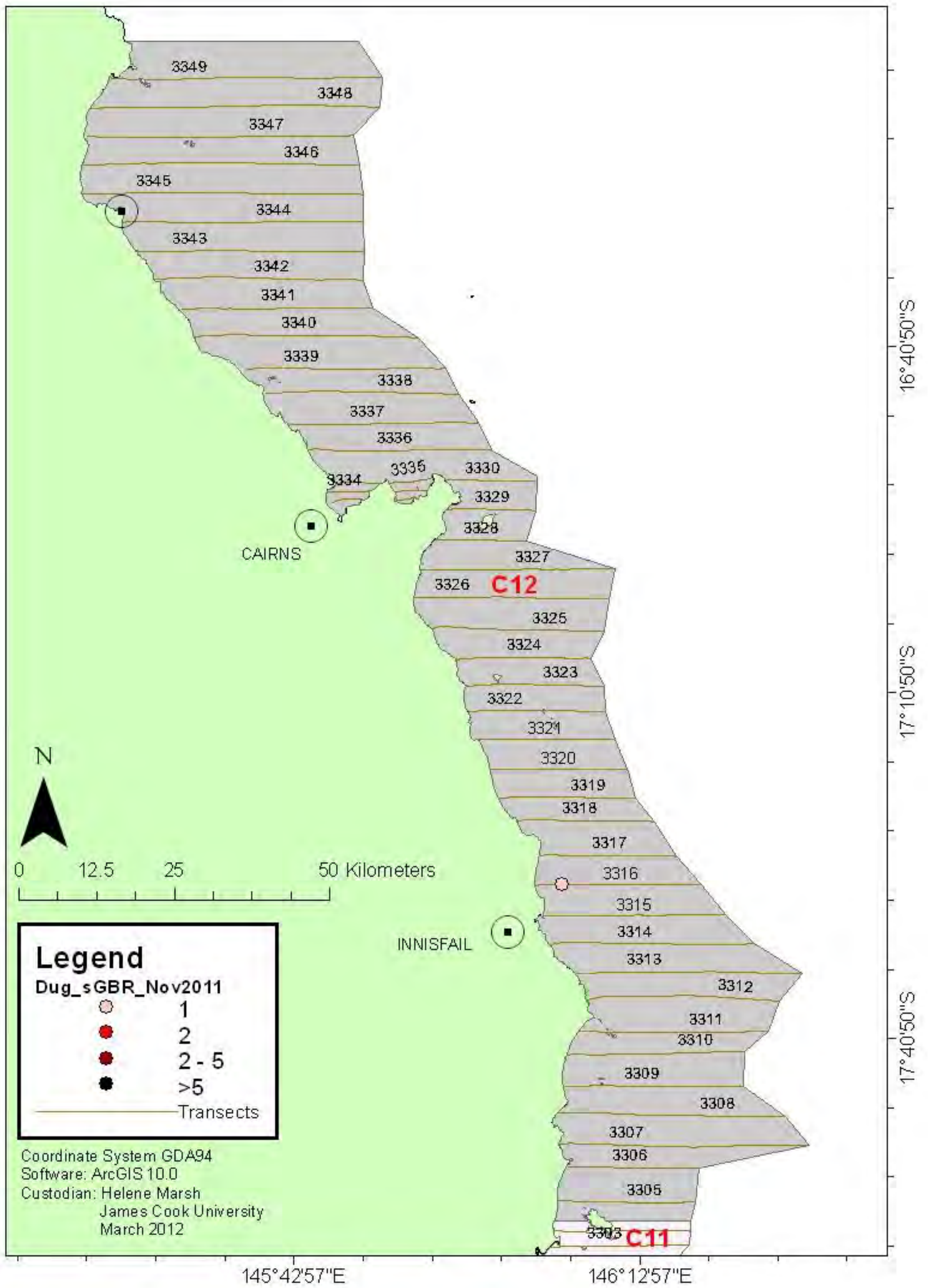
Appendix Figure 8: GPS tracks of transects (four digit numbers) flown in the blocks C5, C6, C7 and C8 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



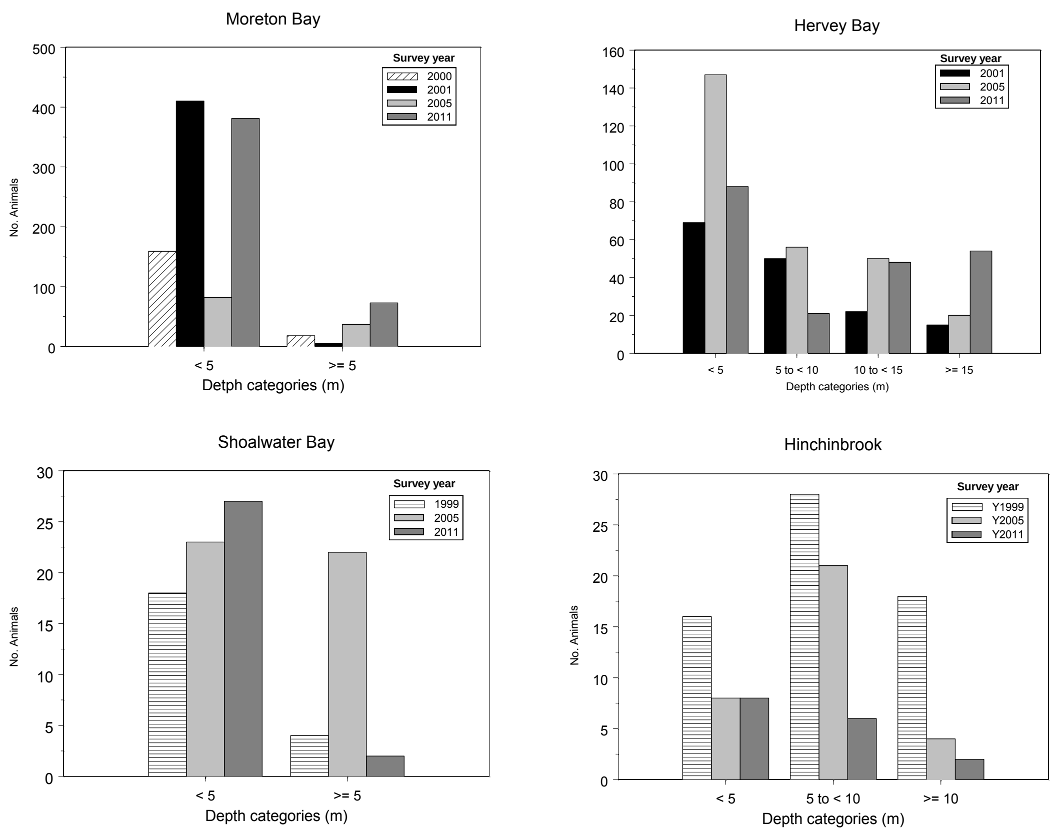
Appendix Figure 9: GPS tracks of transects (four digit numbers) flown in the blocks C9, C10 and C11 (shaded areas, block numbers are in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



Appendix Figure 10: GPS tracks of transects (four digit numbers) flown in the block C12 (shaded area, block number in red) in the southern Great Barrier Reef Region in November 2011 and the positions and sizes of the dugong groups sighted.



Appendix Figure 11: Results of statistical analyses of dugong sightings in Moreton Bay, Hervey Bay, Shoalwater Bay and the Hinchinbrook Island area depending on bathymetry. Sightings had to be grouped to avoid small sample sizes.



Appendix Table 1: Areas of survey blocks and sampling intensities for the aerial survey conducted in November 2011. For locations of blocks see Appendix Figures 1-10. For safety reasons, the 2011 survey was flown at 500 feet as opposed to 450 feet as in previous surveys, resulting in slightly lower sampling intensities.

Block	Block size (km^2)	Area surveyed (km^2)	Sampling intensity (%)
Moreton Bay Region			
1	166	33	19.73
2	691	75	10.91
3	189	13	6.98
4	389	146	37.55
5	155	28	18.11
6	226	43	18.83
Hervey Bay Region			
1	519	87	16.82
2	1415	219	15.49
3	1246	210	16.83
4	1233	105	8.49
5	409	47	11.40
Southern Great Barrier Reef Region			
S1	1054	106	10.06
S2	515	49	9.51
S2A	328	54	16.46
S3	568	100	17.61
S4	2304	232	10.07
S5	1165	222	19.06
S6	3715	300	8.08
S7	736	72	9.78
S8	710	108	15.21
C1	342	64	18.71
C2	332	21	6.33
C3	1701	228	13.40
C4	428	79	18.46
C5	2097	206	9.82
C6	221	43	19.46
C7	557	109	19.57
C8	572	110	19.23
C9	2905	268	9.23
C10	456	93	20.39
C11	675	132	19.56
C12	5511	525	9.53

Appendix Table 2: Weather conditions encountered during the 2011 aerial surveys of Moreton Bay, Hervey Bay and the southern Great Barrier Reef in comparison to the prior surveys of the same areas: historical data from Marsh et al. (1996); Marsh and Lawler (2001); Marsh and Lawler (2007).

	Moreton Bay			Hervey Bay			Southern GBR all sectors		
Year of survey	2011	2005	1999	2011	2005	1999	2011	2005	1994
Max wind speed (km*h-1)	<22	<10	<10	<22	<10	<10	<31	<10	<15
Cloud cover range (oktas)	0-6	0-6	0-3	1-6	1-7	0	0.5-7.5	0-5	0-5
Min. cloud height (ft)	3000	2000	3500	1900	2000	N/A	1450	1000-4000	2000-5000
Mean Beaufort sea state (range)	1.94 (1-3)	1.8 (1-4)	0.87 (0-3)	1.29 (1-3)	2.2 (1-3)	1.67 (0-4)	1.86 (0.5-3)	1.48 (0-4)	1.87 (0-4)
Mean glare North	1.74	1.76	1.42	2.24	1.44	1.92	1.80	1.5	1.44
Mean glare South	1.13	1.23	1.23	1.79	1.27	1.86	1.76	1.5	1.29
Mean glare Overall	1.52	1.49	1.32	2.01	1.35	1.89	1.76	1.5	1.36
Air visibility (km)	N/A	>10	>20	N/A	>10	>30	>8	>10	>15

Appendix Table 3: Beaufort Sea State and Glare for each transect of the 2011 aerial survey for dugongs (Refer to Appendix Figures 1-10 for location of transects).

	Beaufort Sea State			Glare** South/West			Glare** North/East		
Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
Moreton Bay Region Block 0									
1051	1	1	1	1	2	1	1	2.5	1
1052	1	1	1	1	1	1	1	3	3
Moreton Bay Region Block 1									
1040	2	2	2	2	3	2	1.5	2.5	
1041	1	1	1	3	3	3	1	1	1
1042	3	3	3	1	1	1	3	3	3
1043	1	1	1	1	2		2	2	2
1044	1	1	1	2.5	2.5	2.5	2	2.5	
1045	1	1	1	1	1	1	3	3	3
1046	1	1	1	1	1	1	3	3	3
1047	1	1	1	2	2	2	1	1	1
1048	2	2	2	1	1	1	1	1	1
1049	1	1	1	1	1	1	2	2	2
Moreton Bay Region Block 2									
1037	2.5	2.5	2.5	2	2.5	2	2	3	2
1038	3	3	3	1	2	1	2.5	3	
1039	3	3	3	2.5	2.5	2.5	2.5	3	3
1041	1	1	1	1	3	1	3	3	3
1043	2	2	2	1	3	1	1	3	
1045	1	1	1	1	1	1	1	3	3
1047	1	1	1	1	1	1	1	1.5	1
1049	1.5	1.5	1.5	1	2	1	1	3	1
Moreton Bay Region Block 3									
1021	1	1	1	1	1	1	1	1	1
1025	1.5	1.5	1.5	0	1		1	1	1
1029	2	2	2	1	1	1	2	2	2
1033	2.5	2.5	2.5	1	1	1	1	1	1
Moreton Bay Region Block 4									
1015	1	1	1	0	0	0	0	1	
1016	1	1	1	1	1	1	1	2	1
1017	1	1	1	0	1	1	1	3	2
1018	1	1	1	1	2	1	1	2	2
1019	1	1	1	0	1	1	1	1	1
1020	1	1	1	0	1	1	1	3	

1021	1	1	1	0	1		1	1	1
1022	1	1	1	0	1	1	1	2	1
1023	1.5	1.5	1.5	1	1	1	2	2	2
1024	1.5	1.5	1.5	1	1	1	2	3	2
1025	1.5	1.5	1.5	1	1	1	2	2	2
1026	1.5	1.5	1.5	1	1	1	2	2	2
1027	1.5	1.5	1.5	1	1	1	1	1	1
1028	2	2	2	1	2		1	1	1
1029	1.5	2		1	1	1	1	2	2
1030	2	2	2	1	1	1	1.5	2	2
1031	2	2	2	1	1	1	1.5	2	1.5
1032	2	2	2	1	1.5	1	0.5	1	1
1033	2.5	2.5	2.5	1	1	1	1	1	1
1034	2	2	2	1	1	1	1	1.5	1.5
1035	2	2	2	1	3	3	1	3	
Moreton Bay Region Block 5									
1023	1.5	1.5	1.5	1	1	1	3	3	3
1025	1.5	1.5	1.5	1	1	1	2	2	2
1027	1.5	1.5	1.5	1	1	1	1	1	1
1029	2	2	2	1	1	1	3	3	3
1031	2	2	2	1	1	1	2	2	2
1033	2	2	2	1	1	1	1	1	1
1035	2	2	2	2	3		2.5	3	
Moreton Bay Region Block 6									
1003	1	1	1	0	0	0	0	0	0
1004	1	1	1	1	1	1	1	1	1
1005	1	1	1	0	0	0	1	1	1
1006	1	1	1	0	0	0	1	1	1
1007	1	1	1	0	1		0	1	
1008	1	1	1	1	1	1	1	1	1
1009	1	1	1	1	1	1	0	1	
1010	1	1	1	0	1		1	1	1
1011	1	1	1	0	1	1	1	2	1
1012	1	1	1	0	3	1	1	3	1
1013	1	1	1	0	2		1	2	2
1014	1	1	1	1	1	1	1	2	
Moreton Bay Region Block 7									
1036	1.5	2.5							
Moreton Bay Region Block 8									
1001	1	2		1	2	1	2	3	3
1002	2	2	2	1	3	2	3	3	3
Hervey Bay Region Block 1									
2021	1	1	1	1	1	1	1	1	1
2022	1	1	1	1	1	1	1	1	1
2023	1	1	1	1	2		1	1	1
2024	1	1	1	1	1	1	1	1	1
2025	1	1	1	1	2		2	2	2
2026	1	1	1	1	1	1	1	1	1
2027	1	1	1	1	1	1	2	2	2
2028	1	1	1	1	2		1	2	
2029	1	1	1	1	1	1	1	2	
2030	1	1	1	2	2	2	1	2	
2031	1	1	1	1	2		1	3	
2032	1	1	1	1	1	1	1	3	1
2033	1	1	1	1	2		1	3	
2034	1	1	1	1	2		1	2	
2035	1	1	1	1	1	1	1	1	1
2036	1	1	1	1	1	1	1	2	
2037	1	1	1	1	1	1	0	0	0
2038	1	1	1	1	1	1	1	2	

2039	1	1	1	1	1	1	1	2	
2040	1	1	1	0	1		1	2	
2041	1	1	1	1	1	1	1	1	1
2042	1	1	1	1	1	1	2	2.5	
2043	1	1	1	1	1	1	1	1	1
2044	1	1	1	2	2	2	2.5	2.5	2.5
2045	1	1	1	1	1	1	1	1	1
2046	1	1	1	1	2	1	1	3	
2047	1	1	1	2	2	2	2	3	2
2048	1	1	1	1	2		3	3	3
2049	1	1	1	1	3	1	1	3	
2050	1	1	1	1	1	1	2	3	3
Hervey Bay Region Block 2									
2051	1	1	1	1	1	1	1	2	
2052	1	1	1	1	1	1	2	3	2
2053	1	1	1	1	2	1	2	2	2
5254	1	1	1	1	1	1	2	3	2
2055	1	1	1	1	2	1	1	2	2
2056	1	1	1	1	1	1	2	2	2
2057	1	1	1	2	2	2	1	2	2
2058	1	1	1	1	3	1	1	3	
2059	1	1	1	1	3	2	1	3	2
2060	1	1	1	1	3	2	1	3	2
2061	0.5	0.5	0.5	1	3	2	1	3	2
2062	1	1	1	1	3	2	2	3	2
Hervey Bay Region Block 3									
2063	1	1	1	2	3	3	2	3	3
2064	1	1	1	1	3		2	3	2
2065	1.5	1.5	1.5	1	3	1	1	3	2
2066	1.5	1.5	1.5	1	3		1	3	
2067	1	1	1	1	3	3	3	3	3
2068	1.5	1.5	1.5	1	2	1	2.5	3	3
2069	2	2	2	2.5	3	2.5	2	3	3
2070	2.5	2.5	2.5	1	3	2	3	3	3
Hervey Bay Region Block 4									
2063	1	1	1	2	3	2	2	3	2
2064	2	2	2	1	2	2	2	3	3
2065	2	2	2	1	2.5	1	2	3	2
2066	1.5	1.5	1.5	1	2	2	2	3	3
2067	1	1	1	3	3	3	3	3	3
2068	1.5	1.5	1.5	1	2	1	2	2.5	2
2069	2	2	2	1.5	3	2.5	1	2	2
2070	2.5	2.5	2.5	1	2	1	3	3	3
Hervey Bay Region Block 5									
2071	2	2	2	1	1	1	2.5	3	3
2072	1.5	1.5	1.5	2	3	2	2	3	3
2073	1.5	1.5	1.5	1	3	3	3	3	3
2074	1.5	1.5	1.5	2.5	2.5	2.5	3	3	3
2075	1.5	1.5	1.5	2	3	2.5	2.5	3	2.5
Hervey Bay Region Block 6									
2076	2	2	2	1	2	1	1	3	3
2077	1.5	1.5	1.5	1	1	1	3	3	3
2078	1.5	1.5	1.5	1	1	1	3	3	3
Southern Great Barrier Reef Region Block S1									
3001	1.5	1.5	1.5	2	2.5	2.5	2.5	3	3
3002	1.5	1.5	1.5	2	3	2	2	3	2
3003	1.5	1.5	1.5	1	2	2	1.5	2.5	
3004	1.5	1.5	1.5	1.5	2	2	1	2	
3005	1.5	1.5	1.5	1.5	2.5		2	2.5	2.5
3006	1.5	1.5	1.5	2	3	3	1.5	2.5	

3007	1.5	1.5	1.5	2.5	3		2	2.5	
3008	2	2	2	2	2.5	2.5	1.5	2	2
3009	2	2	2	1	2	2	2	2.5	2
3010	2	2	2	2	2.5	2.5	2	2.5	
3011	2	2	2	2	2	2	2.5	3	3
3013	2	2	2	2	3	2	2	2.5	
3015	1.5	1.5	1.5	2	2	2	2.5	3	
3017	1	1	1	1	1.5	1.5	1	1.5	1
Southern Great Barrier Reef Region Block S2									
3023	1	1	1	2	3		2.5	3	
3025	1	1	1	2	3		2.5	3	
3027	1	1	1	2	2.5		2.5	2.5	2.5
3029	1	1	1	2	2.5	2	2	2	2
3030	2	2	2	2	2.5		2.5	2.5	2.5
3031	1	1	1	2	2	2	2	2	2
3032	1	1	1	2	2.5		2.5	2.5	2.5
3033	1.5	1.5	1.5	1	1	1	2	3	
3034	1.5	1.5	1.5	2	2	2	2	2	2
Southern Great Barrier Reef Region Block S2A									
3034	1	1.5		2	2	2	1	2	
3035	1	1	1	1	1	1	1	1	1
3036	1.5	1.5	1.5	1	2		1	1	1
3037	1.5	1.5	1.5	1	1	1	1	1	1
3038	1.5	1.5	1.5	1	2		1	1	1
3039	1.5	1.5	1.5	1	2		1	2	
3040	1.5	1.5	1.5	2	2	2	1	2	
3041	2	2	2	1	1	1	2	2	2
3042	1.5	2	1.5	1	2	1	1	1	1
Southern Great Barrier Reef Region Block S3									
3012	1	1	1	2	2	2	2	2	2
3013	2	2	2	2	2.5		2	2	2
3014	1	1	1	1	2		2.5	3	
3015	1.5	1.5	1.5	2	2.5	2	2.5	3	3
3016	1.5	2.5		2	2.5	2.5	2	2.5	2.5
3017	1	1	1	1	2.5	1	1	2	1
3018	1	1	1	1	2		1	2.5	1
3019	1	1	1	1	2.5	1.5	1	3	
3020	1	1	1	1	3	2	1	2.5	1
3021	1	1	1	1	3		1	3	
3022	0.5	0.5	0.5	1	3		1	3	
3023	0.5	0.5	0.5	1	3		1	3	
3024	0.5	0.5	0.5	1	2	2	1	2	1
3025	0.5	0.5	0.5	1	1.5	1.5	1	1.5	1.5
3026	0.5	0.5	0.5	2.5	2.5	2.5	2	2	2
3027	0.5	0.5	0.5	1	2		2	2.5	
3028	1	1	1	1	1	1	2	2	2
Southern Great Barrier Reef Region Block S4									
3043	1.5	1.5	1.5	1	1	1	2	2	2
3044	1.5	1.5	1.5	1	2	2	1	1	1
3045	1.5	1.5	1.5	1	2	2	1	2	2
3046	1.5	1.5	1.5	1	3		1	2	2
3047	2	2.5		3	3	3	2	3	
3048	2	2	2	3	3	3	2	2	2
3049	2	2	2	2	2	2	2	3	
3050	2	2.5		2	3		2	3	
3051	2	2	2	2	3		3	3	3
3052	2	2	2	3	3	3	3	3	3
3053	2	2	2	3	3	3	3	3	3
3054	2	2	2	2	3		2	3	
3055	2	2	2	2	2	2	3	3	3

3056	2	2	2	3	3	3	2	2	2
3057	1.5	1.5	1.5	1	2		2	3	
3058	1.5	1.5	1.5	2	2	2	1	3	
3059	2	2.5		3	3	3	2	3	
3060	2	2	2	3	3	3	1	2	
3061	2	2	2	2	3		1	2	
3062	1.5	2.5		3	3	3	2	2	2
3063	1.5	2		1	2		2	2	2
3064	2	2	2	3	3	3	2	2	2
3068	1.5	2		2	3		2	3	
3072	1.5	1.5	1.5	3	3	3	2	2	2
3073	2	2	2	3	3	3	3	3	3
3074	1	1.5		3	3	3	2	2	2
3075	1.5	1.5	1.5	1	1	1	2	2	2
3076	2	2	2	2	2	2	3	3	3
3077	1.5	1.5	1.5	3	3	3	2	2	2
3078	1.5	2.5	1.5	2	3	3	1	2	2
3079	1.5	1.5	1.5	1	1	1	3	3	3
3080	1.5	2		2	2	2	2	3	
3100	2	2	2	2	2	2	3	3	3
Southern Great Barrier Reef Region Block S5									
3063	1.5	2		1	2		2	2	2
3064	1.5	1.5	1.5	3	3	3	1	1	1
3065	1	1	1	1	1	1	2	2	2
3066	1.5	1.5	1.5	3	3	3	2	2	2
3067	1.5	1.5	1.5	2	2	2	2	2	2
3068	1.5	1.5	1.5	2	2	2	3	3	3
3069	1	1	1	3	3	3	2	2	2
3070	1.5	1.5	1.5	2	2	2	2	2	2
3071	1.5	1.5	1.5	3	3	3	1	2	
3072	1.5	1.5	1.5	3	3	3	2	2	2
3081	1.5	1.5	1.5	3	3	3	2	2	2
3082	2	2	2	2	2	2	2	2	2
3083	1.5	1.5	1.5	2	2	2	3	3	3
3084	1.5	1.5	1.5	3	3	3	2	2	2
3085	1.5	1.5	1.5	3	3	3	3	3	3
3086	1.5	2		3	3	3	2	2	2
3087	1.5	2		2	3		2	3	
3088	1.5	1.5	1.5	3	3	3	2	3	
3089	1.5	1.5	1.5	2	3		3	3	3
3090	1.5	1.5	1.5	2	3	3	2	2	2
3091	1.5	1.5	1.5	2	3		3	3	3
3092	1.5	1.5	1.5	2	3	3	1	3	
3093	1.5	1.5	1.5	2	2	2	2	3	3
3094	1.5	2		2	3		1	3	2
3095	1.5	1.5	1.5	2	3	3	1	3	
3096	1.5	2	1.5	1	3		3	3	3
3097	1.5	2		2	4		2	2	2
3098	1.5	2		2	4	2	2	3	3
3099	2	2	2	2	3	2	2	3	3
3100	2	2	2	2	2	2	2	2	2
3399	1.5	1.5	1.5	2	2	2	2	2	2
Southern Great Barrier Reef Region Block S6									
3101	1.5	2	2	2	3	3	1	3	
3103	1	1	1	1	1	1	2	2	2
3105	1.5	1.5	1.5	2	2	2	1	1	1
3107	1	1.5		1	2		1	1	1
3109	1.5	1.5	1.5	1	2	2	1	1	1
3111	1.5	1.5	1.5	2	3	3	2	3	2
3113	1.5	1.5	1.5	2	3	3	2	3	2

3114	1.5	2	1.5	2	2	2	2	3	
3115	1.5	2	1.5	1	2	2	2	2.5	2
3116	1.5	1.5	1.5	1	2	1.5	2.5	3	3
3117	1.5	1.5	1.5	2	3		2	2	2
3118	1.5	1.5	1.5	1	1.5	1.5	2.5	3	3
3119	1.5	2		2	2.5	2	2.5	3	2.5
3120	1.5	1.5	1.5	1.5	2.5		3	3	3
3121	1.5	1.5	1.5	2	3		2	3	
3122	1.5	1.5	1.5	1.5	2	2	3	3	3
3123	1.5	1.5	1.5	2	3	2.5	2	2.5	2.5
3124	1.5	1.5	1.5	2	2.5	2	3	3	3
3125	1.5	1.5	1.5	2	3		2	3	3
3126	1.5	1.5	1.5	2	3	3	2	3	3
3127	1	1	1	3	3	3	3	3	3
3128	1	1	1	3	3	3	2.5	3	2.5
3129	1.5	1.5	1.5	1.5	3	2	2	2	2
3131	1	1	1	2	2	2	2	3	
3132	1	1	1	2.5	3	3	2	3	3
3133	2	2	2	2	3	3	2	2	2
Southern Great Barrier Reef Region Block S7									
3134	1.5	1.5	1.5	1.5	2	2	2	2	2
3135	2	2	2	3	3	3	2	2	2
3136	2	2	2	2	2	2	1.5	2	2
3137	2	2	2	1	2	2	2	2	2
3138	2	2	2	2	3	2.5	2	2	2
3139	2	2	2	2	3		2	2	2
3140	2	2	2	2.5	2.5	2.5	1.5	1.5	1.5
3141	2.5	2.5	2.5	3	3	3	2.5	3	
3142	2.5	2.5	2.5	2.5	3		2	2	2
3143	2.5	2.5	2.5	1	3	1	2	3	
Southern Great Barrier Reef Region Block S8									
3144	2	2	2	2	3	3	2	3	2
3145	2.5	2.5	2.5	2	3		2.5	3	3
3146	2	2	2	2	2	2	2	2.5	2
3147	2	2	2	2	3		2.5	3	3
3148	1.5	1.5	1.5	2	2.5	2	2	2	2
3149	2	2	2	2	2	2	2	2.5	2
3150	1.5	1.5	1.5	2.5	3	2.5	1	2	2
3151	1.5	1.5	1.5	2	2	2	2	3	2
3152	1.5	1.5	1.5	2.5	3	2.5	2	2	2
3153	1.5	1.5	1.5	2	2	2	2	2.5	
3154	1.5	2		2.5	3	2.5	2	2	2
3155	1.5	1.5	1.5	2	2.5	2	2	3	3
Southern Great Barrier Reef Region Block C1									
3156	1.5	1.5	1.5	2	3		2	2	2
3157	1	1	1	2	2	2	3	3	3
3158	1.5	1.5	1.5	1	2	2	2	3	
3159	2	2	2	2	2	2	2	2	2
3160	2	2	2	2	2.5	2.5	1.5	2	2
3161	3	3	3	2	2.5	2.5	1	3	
3162	3	3	3	1.5	3	1.5	3		
3163	3	3	3	2.5	3	2.5	2	2.5	2
3164	2	2	2	3	3	3	3	3	3
Southern Great Barrier Reef Region Block C2									
3194	2	2.5	2	0	3	0	3	3	3
Southern Great Barrier Reef Region Block C3									
3165	2.5	2.5	2.5	2	2.5	2.5	2.5	2	2
3166	2.5	2.5	2.5	2.5	2.5	2.5	2	2	2
3167	2	2	2	2	3	3	1.5	3	
3169	2.5	2.5	2.5	2.5	2.5	2.5	2	2.5	

3170	2.5	2.5	2.5	3	3	3	3	3	3
3172	2	2	2	2	3		1	3	
3173	1.5	1.5	1.5	2	3	2	2	2.5	2
3174	1.5	1.5	1.5	2	3	2	2	3	2
3175	2	2	2	1	2.5		2	2.5	2.5
3176	1.5	1.5	1.5	2.5	3		2	3	
3177	1.5	1.5	1.5	2	2	2	1	1	1
3178	1.5	1.5	1.5	2	2	2	2	3	
3180	1.5	1.5	1.5	2	3	2	1	2	
3182	1.5	2		1	3	2	1	3	
3184	2	2	2	1.5	3	2	1.5	3	2
3185	2	2	2	2	2	2	1.5	3	2
3186	2	2	2	1.5	3	1.5	1	3	
3188	1.5	2.5		0	2	2	2	3	3
3189	2	2	2	0	0	0	1	1	1
3190	2	2.5		1	3	2	0	2	2
3193	1.5	2	2	1	3	1	2	3	2
3195	2	2	2	2	2	2	1	1	1
Southern Great Barrier Reef Region Block C4									
3196	1.5	1.5	1.5	0	3		0	0	0
3197	1.5	2		0	0	0	0	0	0
3198	2	2	2	0	0	0	0	1	1
3199	1	2		0	1		0	0	0
3200	2	2	2	0	1	0	0	2	
3201	2	2	2	1	1	1	1	1	1
3202	1.5	2		0	1	0	0	2	2
3203	1.5	2	2	1	1	1	0	1	
3204	2	2	2	1	1	1	2	3	
3205	2	2	2	1	2	2	1	1	1
Southern Great Barrier Reef Region Block C5									
3206	2	2	2	0	2	1	2	3	
3207	1.5	2		1	1	1	1	2	
3208	2	2	2	1	2	2	2	3	2
3209	2	2.5	2	2	2	2	3	3	3
3210	2	2.5	2	2	2	2	2	3	2
3211	2	2	2	1	2	2	3	3	3
3212	2	2	2	2	3	2	3	3	3
3220	1.5	2.5		1	1	1	2	2	2
3221	2	2.5	2.5	2	3	2	1	2	1
3222	2	2.5		1	1	1	2	3	3
3223	2	2.5	2.5	2	3	2	1	2	1
3224	2	2.5	2	0	3		2	3	2
3225	2.5	2.5	2.5	2	2	2	1	2	2
3226	2	2	2	0	1	1	2	3	3
3227	2.5	2.5	2.5	2	3	2	1	2	2
3228	2	3		2	2	2	2	3	3
3229	2	2.5	2.5	2	2	2	0	3	3
3237	2.5	3	2.5	0	2	1	0	2	2
3238	2	2.5	2.5	0	1	0	1	2	1
3239	2.5	2.5	2.5	0	2	2	0	2	0
Southern Great Barrier Reef Region Block C6									
3213	2	2	2	1	1	1	0	0	0
3214	2	2	2	0	1		1	1	1
3215	1.5	2		1	2		0	0	0
3216	2	2	2	0	1	1	1	2	2
3217	2	2	2	1	2		0	0	0
3218	1.5	2	2	0	0	0	2	2	2
3219	2	2	2	1	1	1	0	1	
Southern Great Barrier Reef Region Block C7									
3230	1.5	2.5	2.5	0	0	0	0	2	

3231	2	2.5	2.5	0	0	0	0	1	0
3232	2	2.5	2.5	0	1	0	0	2	2
3233	2	2.5		0	2		0	1	1
3234	2	2.5	2	1	2	1	1	2	2
3235	2	2.5	2	0	1	0	0	1	1
3236	2	2.5	2.5	0	1		0	3	
Southern Great Barrier Reef Region Block C8									
3240	1	1	1	0	0	0	0	0	0
3241	2	2	2	0	0	0	0	2	
3242	2	2.5	2	0	2		0	0	0
3243	2	2.5	2	0	1	0	0	3	
3244	2.5	2.5	2.5	0	3		0	3	3
3245	1.5	2		0	0	0	1	1	1
3246	2	2	2	0	2	1	0	2	2
3247	2	2.5	2	0	1	1	1	1	1
3248	2.5	2.5	2.5	1	2	2	0	1	1
3149	2	2.5		0	1		0	1	
3250	2	2.5	2	0	2		0	1	1
3251	2	2	2	0	1	0	0	2	0
3252	2.5	3	2.5	0	2	2	3	3	3
Southern Great Barrier Reef Region Block C9									
3253	2.5	3	3	0	3		0	3	1
3254	2	2	2	2	3	3	2	3	2
3255	2	2	2	2	3	3	3	3	3
3256	1.5	2	2	2	3	3	2	3	
3257	2	2	2	0	3		0	2	2
3258	2	2.5	2	0	2	0	0	2	2
3259	1.5	2.5	2	1	2	2	0	1	1
3260	2	2	2	0	1		0	2	0
3261	1.5	2.5	2	0	2	2	0	1	1
3263	1.5	2	2	0	1		0	2	1
3265	2	2	2	0	2	0	0	0	0
3267	2	2	2	0	3	0	0	0	0
3269	1.5	2		0	1		0	2	
3270	2	2.5	2	0	0	0	1	3	2
3271	1.5	2		2	3		2	3	
3272	2	2	2	0	1	0	0	0	0
3275	2	2	2	0	2		0	3	
3276	2	2	2	0	2	2	2	3	2
3277	2	2.5		1	1	1	0	1	
3278	2	2	2	0	1	1	1	1	1
3279	2.5	2.5	2.5	1	2	2	1	1	1
Southern Great Barrier Reef Region Block C10									
3273	1.5	2.5	1.5	0	3	3	0	1	0
3274	1.5	2.5	2	0	3		0	0	0
3280	2	2	2	1	1	1	1	2	
3282	2	2	2	2	2	2	1	1	1
3283	2	2.5		0	0	0	0	0	0
3284	2.5	2.5	2.5	0	0	0	0	0	0
3285	2	2	2	0	0	0	0	0	0
3286	2	2	2	0	0	0	0	0	0
3287	1	2		2	3		0	0	0
3288	1.5	1.5	1.5	0	1		0	0	0
3289	1.5	1.5	1.5	2	3		0	0	0
3290	2	2.5		0	2	0	1	2	1
3291	2	2	2	1	1	1	2	2	2
Southern Great Barrier Reef Region Block C11									
3292	2	2	2	0	2	2	0	1	1
3293	1	1.5	1	0	3	0	1	2	2
3294	2	2	2	0	0	0	1	2	

3295	1	2.5	1	0	1	1	0	2	0
3296	1	2	2	0	0	0	0	1	0
3297	1.5	2		1	1	1	2	2	2
3298	2.5	2.5	2.5	1	2	2	1	1	1
3299	2	2.5	2	1	3		2	3	2
3300	2	2.5		2	2	2	2	2	2
3301	2	2.5		1	2	2	3	3	3
3302	2	2.5		1	2		2	2	2
3303	2	2.5	2	1	2	2	2	3	3
3304	2	2.5		2	3		2	3	
Southern Great Barrier Reef Region Block C12									
3305	2	2	2	1	2	2	2	3	3
3306	2	2.5	2.5	0	3	3	0	3	3
3307	2	2	2	0	3	2	3	3	3
3308	2	2	2	1	2	2	3	3	3
3309	1.5	2	2	1	2	1	0	1	0
3310	1.5	2	2	0	1	1	1	1	1
3311	1.5	2.5	2	2	2	2	1	1	1
3312	2	2	2	1	2	1	0	2	2
3313	2	2.5	2	2	2	2	1	2	
3314	1.5	2		1	2	2	1	2	2
3315	1	2	2	2	2	2	1	2	1
3316	2	2	2	1	2	1	1	2	2
3317	1.5	2	1.5	2	4	2	1	2	2
3318	1.5	2	1.5	1	2	2	2	3	
3319	2	2	2	2	2	2	2	2	2
3320	1.5	2	2	2	3	2	2	2	2
3321	2	2	2	2	3	3	0	3	2
3322	1.5	2	2	2	3	2	2	2	2
3323	1.5	1.5	1.5	0	1	0	1	2	1
3324	2	2	2	0	2		0	0	0
3325	1.5	2	2	0	1		0	2	2
3326	2	2.5	2	0	2	2	0	1	1
3327	2	2.5	2	0	1	1	0	2	2
3328	2	2	2	2	2	2	1	1	1
3329	2	2.5		1	2		2	2	2
3330	2	2	2	0	1		2	3	
3331	1.5	1.5	1.5	0	0	0	2	2	2
3332	1.5	1.5	1.5	2	2	2	1	1	1
3333	1.5	1.5	1.5	2	2	2	0	0	0
3334	1.5	1.5	1.5	1	1	1	0	1	
3335	1.5	1.5	1.5	1	2		0	0	0
3336	1.5	2.5		1	2	2	1	3	
3337	2	2.5		1	3	3	0	3	3
3338	2	2.5		1	3	3	2	3	3
3339	2	2.5	2	1	3	3	2	3	2
3340	1	1.5	1	0	2		0	2	
3341	1	1.5	1	0	1	1	0	0	0
3342	1	1.5	1	0	2	1	0	2	1
3343	1	1.5	1	1	2	1	0	1	0
3344	1	1.5	1	0	2	2	0	2	1
3345	1	1.5		0	3	3	0	3	0
3346	1	1.5	1	0	3	1	0	1	1
3347	1	1.5	1.5	0	3	3	0	2	
3348	1	1.5	1	0	3		0	2	
3349	1	1.5	1.5	0	3	3	0	1	

*Beaufort Sea State: 0 = <1 knot; 1 = 1-3 knots; 2 = 4-6 knots; 3 = 7-10 knots.
**Glare scale: 0 = no glare; 1 = 0 – 25%; 2 = 25 – 50%; 3 = >50%.

Appendix Table 4: Raw data for sightings of 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 1-10 for position of transects).

Transect	Average height/transect	Transect length (km)	Transect area (km²)	# groups port	# groups starboard
		Moreton Bay Region Block 0			
1051	503	42.8	17.1	0	0
1052	527	90.3	36.1	0	0
		Moreton Bay Region Block 1			
1040	496	14.0	5.6	0	0
1041	500	13.9	5.6	0	0
1042	493	13.0	5.2	0	0
1043	530	12.1	4.8	0	0
1044	580	11.5	4.6	0	0
1045	520	8.9	3.6	0	1
1046	410	2.0	0.8	0	0
1047	500	1.0	0.4	0	0
1048	500	2.0	0.8	0	0
1049	500	1.3	0.5	0	0
		Moreton Bay Region Block 2			
1037	540	32.3	12.9	0	0
1038	488	26.8	10.7	1	0
1039	503	25.1	10.0	0	0
1041	500	20.0	8.0	0	0
1043	520	18.7	7.5	0	0
1045	505	19.1	7.6	0	0
1047	530	15.8	6.3	0	0
1049	517	25.9	10.4	0	0
		Moreton Bay Region Block 3			
1021	500	4.7	1.9	0	0
1025	510	4.0	1.6	0	0
1029	500	9.7	3.9	2	1
1033	500	14.5	5.8	0	0
		Moreton Bay Region Block 4			
1015	500	16.0	6.4	1	0
1016	520	17.9	7.2	2	1
1017	500	18.0	7.2	0	0
1018	505	18.8	7.5	2	0
1019	507	18.5	7.4	1	1
1020*	530	19.6	7.8	1	4
1021	530	19.1	7.7	1	6
1022**	507	19.3	7.7	3	5
1023***	490	16.3	6.5	1	4
1024	480	15.4	6.2	8	3
1025	490	18.9	7.6	0	0
1026	460	17.9	7.1	0	1
1027	490	18.4	7.3	1	0
1028	460	18.1	7.3	1	1
1029	503	17.7	7.1	0	0
1030	463	15.6	6.2	0	0
1031	493	14.8	5.9	0	0
1032	500	16.1	6.4	0	0
1033	500	17.3	6.9	0	0
1034	490	16.4	6.6	1	0
1035	530	16.5	6.6	0	0
		Moreton Bay Region Block 5			
1023	460	6.7	2.7	0	0
1025	500	10.3	4.1	0	0
1027	480	11.8	4.7	0	0

1029	460	11.0	4.4	1	0
1031	500	10.3	4.1	0	0
1033	480	11.1	4.4	0	0
1035	507	11.3	4.5	0	0
Moreton Bay Region Block 6					
1003	520	2.0	0.8	0	0
1004	500	4.6	1.8	0	0
1005	555	4.1	1.6	0	0
1006	545	7.3	2.9	0	0
1007	555	5.8	2.3	0	0
1008	530	8.5	3.4	1	1
1009	600	9.0	3.6	1	2
1010	535	8.8	3.5	2	0
1011	563	12.6	5.0	2	0
1012	530	12.1	4.8	0	1
1013	526	13.4	5.3	0	1
1014	550	9.7	3.9	0	0
Moreton Bay Region Block 7					
1036	512	31.4	12.6	0	0
Moreton Bay Region Block 8					
1001	502	50.4	20.2	0	0
1002	503	41.6	16.6	0	0
Hervey Bay Region Block 0					
2076	517	72.3	28.9	0	0
2077	528	50.5	20.2	0	0
2078	518	33.1	13.3	0	0
Hervey Bay Region Block 1					
2021	480	3.0	1.2	1	0
2022	500	2.7	1.1	0	1
2023	500	3.1	1.2	0	0
2024	480	2.6	1.0	1	0
2025	520	5.4	2.1	3	1
2026	520	6.0	2.4	0	0
2027	500	3.2	1.3	0	0
2028	490	7.2	2.9	0	0
2029	500	8.1	3.2	1	0
2030	540	6.8	2.7	0	1
2031	507	10.3	4.1	3	1
2032	510	7.2	2.9	0	0
2033	510	7.0	2.8	0	0
2034	530	6.7	2.7	0	2
2035	510	6.9	2.8	1	0
2036	520	4.4	1.8	0	0
2037	520	3.1	1.2	0	0
2038	500	5.3	2.1	0	0
2039	510	4.2	1.7	0	0
2040	500	4.4	1.8	0	0
2041	500	6.3	2.5	0	0
2042	510	6.2	2.5	1	0
2043	550	9.6	3.9	1	0
2044	500	8.6	3.4	0	1
2045	450	10.5	4.2	0	2
2046	513	12.8	5.1	1	1
2047	500	13.2	5.3	0	0
2048	520	14.4	5.7	0	0
2049	513	13.8	5.5	2	0
2050	490	12.3	4.9	0	0
Hervey Bay Region Block 2					
2051	510	21.1	8.4	1	0
2052	493	34.6	13.8	1	3

2053	500	34.2	13.7	0	0
2054	500	36.4	14.6	2	1
2055****	482	40.0	16.0	0	0
2056	495	43.2	17.3	2	2
2057	497	46.1	18.4	2	1
2058	494	53.2	21.3	7	5
2059	494	57.7	23.1	5	9
2060	482	61.4	24.6	5	12
2061	477	64.0	25.6	1	0
2062	481	67.2	26.9	1	0
Hervey Bay Region Block 3					
2063	478	37.1	14.8	0	0
2064	490	38.3	15.3	0	0
2065	478	38.1	15.2	0	0
2066	491	35.5	14.2	2	0
2067	490	32.2	12.9	1	0
2068	507	28.3	11.3	0	0
2069	503	32.2	12.9	0	0
2070	492	37.8	15.1	0	0
Hervey Bay Region Block 4					
2063	473	35.2	14.1	1	2
2064	468	36.8	14.7	1	0
2065	493	36.2	14.5	1	0
2066	480	37.1	14.8	0	0
2067	507	38.4	15.3	0	0
2068	472	41.6	16.6	0	0
2069	483	46.1	18.4	0	0
2070	482	35.5	14.2	0	0
Hervey Bay Region Block 5					
2071	484	23.1	9.2	0	0
2072	500	14.3	5.7	0	0
2073	513	15.5	6.2	0	0
2074	475	15.0	6.0	0	0
2075	483	16.0	6.4	0	0
Southern Great Barrier Reef Region Block S1					
3001	487	17.3	6.9	0	0
3002	488	19.0	7.6	0	0
3003	493	16.4	6.6	0	0
3004	487	16.6	6.6	0	0
3005	493	16.5	6.6	0	0
3006	493	15.3	6.1	0	0
3007	480	14.0	5.6	0	0
3008	497	14.3	5.7	0	0
3009	500	15.4	6.2	0	0
3010	510	17.5	7.0	0	0
3011	493	16.6	6.6	0	0
3013	510	20.1	8.0	0	0
3015	505	21.6	8.6	0	0
3017	513	20.1	8.0	0	0
Southern Great Barrier Reef Region Block S2					
3023	500	9.3	3.7	0	0
3025	510	13.5	5.4	0	0
3027	500	16.4	6.5	0	0
3029	493	17.5	7.0	0	0
3030	490	13.6	5.4	0	0
3031	500	11.3	4.5	0	0
3032	475	10.8	4.3	0	0
3033	505	10.3	4.1	0	0
3034	500	9.5	3.8	0	0
Southern Great Barrier Reef Region Block S2A					

3034	500	8.7	3.5	0	0
3035	510	12.2	4.9	0	0
3036	500	13.5	5.4	0	0
3037	505	7.3	2.9	0	0
3038	510	16.4	6.5	0	0
3039	500	19.8	7.9	0	0
3040	505	12.9	5.2	0	0
3041	510	11.9	4.8	0	0
3042	503	16.7	6.7	0	0
Southern Great Barrier Reef Region Block S3					
3012	483	8.5	3.4	0	0
3013	510	13.1	5.2	0	0
3014	535	11.5	4.6	0	0
3015	513	13.0	5.2	0	0
3016	513	19.5	7.8	0	0
3017	458	19.7	7.9	0	0
3018	493	18.3	7.3	0	0
3019	505	19.5	7.8	0	0
3020	510	24.0	9.6	0	0
3021	500	22.3	8.9	0	0
3022	500	8.6	3.4	0	0
3023	510	9.6	3.8	0	0
3024	487	16.4	6.6	0	0
3025	490	13.7	5.5	0	0
3026	460	4.7	1.9	0	0
3027	500	2.0	0.8	0	0
3028	400	1.2	0.5	0	0
Southern Great Barrier Reef Region Block S4					
3043	507	24.6	9.8	0	0
3044	507	26.0	10.4	0	0
3045	497	24.0	9.6	0	0
3046	500	22.3	8.9	0	0
3047	505	19.5	7.8	0	0
3048	500	21.7	8.7	0	0
3049	500	19.1	7.6	0	0
3050	505	20.4	8.1	0	0
3051	500	17.1	6.8	0	0
3052	500	16.9	6.8	0	0
3053	500	16.0	6.4	0	0
3054	500	16.7	6.7	0	0
3055	500	15.2	6.1	0	0
3056	505	15.6	6.2	0	0
3057	500	14.8	5.9	0	0
3058	500	15.1	6.0	0	0
3059	505	14.2	5.7	0	0
3060	505	13.1	5.2	0	0
3061	510	14.6	5.8	0	0
3062	500	16.4	6.6	0	0
3063	500	15.6	6.2	0	0
3064	500	15.7	6.3	0	0
3068	505	14.5	5.8	0	0
3072	500	13.3	5.3	0	0
3073	500	8.8	3.5	0	0
3074	505	10.6	4.2	0	0
3075	500	2.3	0.9	0	0
3076	500	9.7	3.9	0	0
3077	510	1.7	0.7	0	0
3078	500	18.2	7.3	0	0
3079	510	12.7	5.1	0	0
3080	500	14.4	5.7	0	0

3100	500	18.7	7.5	0	0
Southern Great Barrier Reef Region Block S5					
3063	500	2.0	0.8	0	0
3064	500	2.0	0.8	0	0
3065	500	3.1	1.2	0	0
3066	500	3.7	1.5	0	0
3067	500	8.2	3.3	1	1
3068	490	7.3	2.9	0	0
3069	500	8.1	3.3	0	0
3070	500	10.0	4.0	0	0
3071	500	8.5	3.4	0	0
3072	510	2.6	1.0	0	0
3081	500	1.0	0.4	0	0
3082	510	0.8	0.3	0	0
3083	510	4.2	1.7	0	0
3084	500	7.1	2.8	0	0
3085	500	15.1	6.1	0	1
3086	505	14.1	5.7	1	0
3087	500	16.1	6.4	0	0
3088	505	18.0	7.2	0	0
3089	505	21.8	8.7	1	0
3090	500	24.7	9.9	0	0
3091	505	29.6	11.8	4	3
3092	503	27.4	11.0	0	1
3093	500	32.2	12.9	2	0
3094	503	26.6	10.6	0	0
3095	500	31.8	12.7	1	1
3096	500	31.1	12.4	0	0
3097	505	32.3	12.9	0	0
3098	500	33.2	13.3	0	0
3099	507	34.5	13.8	0	0
3100	500	38.9	15.6	0	0
3399	510	1.6	0.6	0	0
Southern Great Barrier Reef Region Block S6					
3101	500	55.6	22.2	0	0
3103	490	2.4	1.0	0	0
3105	500	8.4	3.3	0	0
3107	500	15.5	6.2	0	0
3109	500	28.6	11.4	0	0
3111	497	31.4	12.6	0	0
3113	510	35.6	14.2	0	0
3114	510	60.4	24.1	0	0
3115	490	64.7	25.9	0	0
3116	496	60.9	24.4	0	0
3117	490	18.1	7.3	0	0
3118	467	19.4	7.8	0	0
3119	515	21.3	8.5	0	0
3120	487	21.3	8.5	0	0
3121	470	20.9	8.4	0	0
3122	507	24.7	9.9	0	0
3123	490	25.1	10.0	0	0
3124	487	20.6	8.2	0	0
3125	480	22.0	8.8	0	0
3126	500	18.8	7.5	0	0
3127	473	16.4	6.5	0	0
3128	500	21.0	8.4	0	0
3129	495	20.3	8.1	0	0
3131	513	18.8	7.5	0	0
3132	500	13.5	5.4	0	0
3133	487	15.2	6.1	0	0

Southern Great Barrier Reef Region Block S7					
3134	493	15.6	6.2	0	0
3135	500	13.1	5.2	0	0
3136	483	17.5	7.0	0	0
3137	495	23.2	9.3	0	0
3138	478	21.0	8.4	0	0
3139	480	12.5	5.0	0	0
3140	460	11.2	4.5	0	0
3141	490	14.8	5.9	0	0
3142	495	17.7	7.1	0	0
3143	477	19.5	7.8	0	0
Southern Great Barrier Reef Region Block S8					
3144	508	21.8	8.7	0	0
3145	533	20.1	8.0	0	0
3146	513	14.5	5.8	0	0
3147	493	16.4	6.6	0	0
3148	510	22.0	8.8	1	2
3149	520	16.7	6.7	0	0
3150	513	19.1	7.6	0	0
3151	478	23.4	9.4	0	0
3152	510	19.5	7.8	0	1
3153	510	21.6	8.7	0	0
3154	513	21.4	8.6	0	0
3155	507	22.1	8.8	0	0
Southern Great Barrier Reef Region Block C1					
3156	507	18.6	7.4	0	0
3157	533	20.8	8.3	0	0
3158	490	20.3	8.1	0	0
3159	513	19.2	7.7	0	0
3160	507	20.9	8.4	0	0
3161	493	15.4	6.2	0	0
3162	560	11.7	4.7	0	0
3163	500	10.4	4.2	0	0
3164	440	2.8	1.1	1	0
Southern Great Barrier Reef Region Block C2					
3194	504	46.8	18.7	0	1
Southern Great Barrier Reef Region Block C3					
3165	520	21.0	8.4	0	0
3166	525	14.5	5.8	0	0
3167	487	17.7	7.1	0	0
3169	520	18.3	7.3	1	0
3170	475	20.1	8.0	0	0
3172	453	18.7	7.5	0	0
3173	484	27.1	10.8	0	0
3174	500	19.1	7.6	0	0
3175	500	22.0	8.8	1	0
3176	480	6.4	2.5	0	0
3177	468	23.8	9.5	0	0
3178	510	12.7	5.1	0	0
3180	520	25.3	10.1	0	0
3182	473	33.9	13.6	0	0
3184	485	38.8	15.5	0	0
3185	480	30.9	12.4	0	1
3186	485	33.2	13.3	0	0
3188	508	36.0	14.4	0	0
3189	510	5.7	2.3	0	0
3190	505	33.8	13.5	1	0
3193	505	41.4	16.5	0	0
3195	500	19.7	7.9	0	0

Southern Great Barrier Reef Region Block C4					
3196	500	12.5	5.0	0	0
3197	500	16.4	6.6	1	0
3198	503	15.6	6.2	0	0
3199	495	16.5	6.6	0	0
3200	497	19.7	7.9	0	0
3201	500	22.4	9.0	0	0
3202	508	19.0	7.6	0	0
3203	500	17.7	7.1	0	0
3204	500	17.8	7.1	1	0
3205	503	19.1	7.6	0	0
Southern Great Barrier Reef Region Block C5					
3206	505	20.9	8.3	0	0
3207	505	6.4	2.6	0	0
3208	503	42.7	17.1	0	0
3209	503	19.5	7.8	1	0
3210	503	19.0	7.6	0	0
3211	503	19.2	7.7	0	0
3212	503	24.5	9.8	0	0
3220	500	19.0	7.6	1	0
3221	507	19.3	7.7	0	0
3222	505	20.1	8.0	0	0
3223	500	19.5	7.8	0	0
3224	503	19.8	7.9	0	0
3225	500	19.4	7.8	0	0
3226	503	19.9	8.0	0	0
3227	508	19.2	7.7	0	0
3228	507	19.8	7.9	0	0
3229	507	20.9	8.4	0	0
3237	500	36.0	14.4	0	0
3238	504	36.1	14.4	0	0
3239	506	38.1	15.2	0	0
Southern Great Barrier Reef Region Block C6					
3213	500	9.2	3.7	1	1
3214	505	10.3	4.1	1	1
3215	500	12.9	5.2	0	1
3216	497	14.0	5.6	0	0
3217	505	15.9	6.4	0	0
3218	497	17.1	6.8	0	0
3219	505	16.3	6.5	0	0
Southern Great Barrier Reef Region Block C7					
3230	496	25.9	10.4	0	0
3231	500	35.6	14.2	0	0
3232	503	37.2	14.9	0	0
3233	498	37.4	15.0	0	1
3234	502	37.3	14.9	0	0
3235	490	37.0	14.8	0	0
3236	510	34.5	13.8	0	0
Southern Great Barrier Reef Region Block C8					
3240	500	9.5	3.8	0	1
3241	503	14.9	5.9	0	0
3242	508	14.7	5.9	0	0
3243	507	15.9	6.4	0	0
3244	500	24.5	9.8	0	0
3245	500	25.9	10.4	0	0
3246	500	20.6	8.3	0	0
3247	500	21.0	8.4	0	0
3248	497	20.7	8.3	0	0
3249	500	15.1	6.0	0	0
3250	503	19.5	7.8	0	0

3251	502	18.7	7.5	0	0
3252	507	24.6	9.8	0	0
Southern Great Barrier Reef Region Block C9					
3253	506	38.7	15.5	0	0
3254	510	41.7	16.7	0	0
3255	505	42.9	17.1	0	0
3256	505	48.0	19.2	0	0
3257	507	46.2	18.5	0	0
3258	503	48.0	19.2	0	0
3259	498	46.0	18.4	0	0
3260	507	43.1	17.2	0	0
3261	504	28.9	11.5	0	0
3263	503	27.2	10.9	0	0
3265	500	17.6	7.0	0	0
3267	500	10.7	4.3	0	0
3269	500	14.3	5.7	0	0
3270	500	31.7	12.7	0	0
3271	505	15.3	6.1	0	0
3272	500	20.9	8.4	0	0
3275	500	14.0	5.6	0	0
3276	507	11.2	4.5	0	0
3277	510	13.5	5.4	0	0
3278	497	17.3	6.9	0	0
3279	497	20.7	8.3	0	0
Southern Great Barrier Reef Region Block C10					
3273	490	34.1	13.7	0	1
3274	505	37.7	15.1	0	2
3280	500	22.5	9.0	0	0
3282	500	20.4	8.1	0	0
3283	500	11.7	4.7	0	0
3284	510	2.7	1.1	0	0
3285	500	9.2	3.7	0	0
3286	500	9.4	3.7	0	0
3287	500	8.7	3.5	0	1
3288	500	6.9	2.8	0	0
3289	500	3.1	1.2	0	0
3290	498	22.3	8.9	0	5
3291	500	21.8	8.7	0	0
Southern Great Barrier Reef Region Block C11					
3292	503	42.3	16.9	0	3
3293	503	15.8	6.3	0	1
3294	505	22.7	9.1	0	0
3295	503	28.7	11.5	1	0
3296	500	21.0	8.4	0	0
3297	480	21.4	8.5	0	0
3298	503	21.2	8.5	0	0
3299	500	21.1	8.4	0	0
3300	495	20.0	8.0	0	0
3301	500	21.2	8.5	0	0
3302	500	20.2	8.1	0	0
3303	504	21.3	8.5	0	0
3304	505	20.2	8.1	0	0
Southern Great Barrier Reef Region Block C12					
3305	508	21.1	8.4	0	0
3306	508	20.1	8.0	0	0
3307	506	38.4	15.4	0	0
3308	503	34.8	13.9	0	0
3309	500	27.6	11.1	0	0
3310	503	27.2	10.9	0	0
3311	500	29.1	11.6	0	0

3312	505	29.7	11.9	0	0
3313	503	34.7	13.9	0	0
3314	504	31.3	12.5	0	0
3315	500	28.1	11.2	0	0
3316	502	25.6	10.2	1	0
3317	503	21.2	8.5	0	0
3318	505	21.1	8.4	0	0
3319	500	20.9	8.4	0	0
3320	510	21.1	8.4	0	0
3321	503	21.3	8.5	0	0
3322	510	20.4	8.1	0	0
3323	500	21.2	8.5	0	0
3324	503	20.9	8.3	0	0
3325	503	26.4	10.6	0	0
3326	507	30.1	12.0	0	0
3327	502	30.1	12.0	0	0
3328	505	14.0	5.6	0	0
3329	500	13.7	5.5	0	0
3330	500	14.1	5.6	0	0
3331	460	3.5	1.4	0	0
3332	n/a	5.0	2.0	0	0
3333	500	5.0	2.0	0	0
3334	500	6.9	2.8	0	0
3335	495	13.3	5.3	0	0
3336	502	28.5	11.4	0	0
3337	505	29.2	11.7	0	0
3338	503	29.9	12.0	0	0
3339	508	30.8	12.3	0	0
3340	500	34.6	13.8	0	0
3341	503	29.5	11.8	0	0
3342	500	32.3	12.9	0	0
3343	500	35.0	14.0	0	0
3344	500	37.4	14.9	0	0
3345	505	43.4	17.4	0	0
3346	504	43.0	17.2	0	0
3347	503	41.1	16.4	0	0
3348	504	44.8	17.9	0	0
3349	503	41.4	16.6	0	0

*In addition, one herd was sighted with 117 dugongs.

**In addition, one herd was sighted with 170 dugongs.

***In addition, one herd was sighted with 44 dugongs.

****In addition, one herd was sighted with 25 dugongs.

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

Block	Mean group size (C.V.)[1]	Perception correction factor (C.V.)[2]		Availability correction factor (C.V.)
		Port	Starboard	
Moreton Bay Region				
4	1.5 (0.110)	1.053 (0.011)	1.029 (0.006)	1.979 (0.179)
6	1.2 (0.111)			
Hervey Bay Region				
1	1.68 (0.164)	1.053 (0.011)	1.029 (0.006)	2.128 (0.153)
2	1.459 (0.074)			
3	2(0.289)			
4	1 (0)			
Southern GBR Region				
C6	1.2 (0.167)	2.333 (0.672)	1.505 (0.191)	2.182 (0.192)
C10	1 (0)			
C11	1.2 (0.167)			
S5	1.235 (0.110)	1.2 (0.122)	1 (0)	

[1] excluding herds
[2] The Southern Team surveyed the Moreton Bay and the Hervey Bay Regions. The Northern Team, which surveyed the southern GBR Region, had a complete change-over of observers resulting in two different correction factors.

Appendix Table 6: Estimates of dugong numbers (+ SE) for each survey block in Moreton Bay and Hervey Bay for various surveys conducted between 1988-2011 inclusive. The block locations are in Appendix Figures 1 and 2. Historical data from Marsh and Saalfeld (1990a and b); Marsh et al, (1996) and (2004); Marsh and Lawler (2000) and (2007).

	Marsh and Sinclair (1989)				Pollock *et al.* (2006)	
Moreton Bay Region						
Block	1988	1995[#]	2005	2011	2005	2011
M1	tfe	25	97	tfe	95	tfe
		(16)	(18)		(37)	
M2	0	tfe	tfe	tfe	tfe	tfe
M3	0	tfe	298	tfe	301	tfe
			(28)		(43)	
M4	442	921	60	741	26	569
	(69)	(35)	(24)	(59)	(21)	(141)
M5	tfe	0	0	tfe	0	tfe
M6	tfe	22	tfe	142	tfe	131
		(21)		(33)		(66)
M7	0	ns	zzt	0	zzt	0
M8	0	ns	zzt	tfe	zzt	tfe
Total all	**442**	**968**	**454**	**883**	**421**	**700**
blocks	**(69)**	**(44)**	**(41)**	**(68)**	**(60)**	**(156)**

Hervey Bay Region									
Block	1988	1992	1993	1994	1999	2005	2011	2005	2011
H1	269	943	193	287	373	649	585	389	397
	(147)	(377)	(52)	(79)	(96)	(110)	(93)	(130)	(152)
H2	1753	71	257	408	875	1331	1251	1143	1363
	(388)	(40)	(85)	(115)	(196)	(261)	(54)	(353)	(536)
H3	153	tfe	tfe	tfe	113	566	152	545	148
	(59)				(71)	(296)	(5)	(392)	(90)
H4	tfe	74	74	tfe	112	0	128	0	121
		(50)	(50)		(76)		(6)		(116)
H5	ns	ns	ns	tfe	180	0	0	0	0
					(53)				
H6	ns	ns	ns	ns	0	0	0	zzt	0
Total all	**2175**	**1088**	**524**	**695**	**1653**	**2547**	**2116**	**2077**	**2029**
blocks	**(419)**	**(382)**	**(124)**	**(140)**	**(248)**	**(410)**	**(108)**	**(543)**	**(576)**

tfe = too few to estimate (<5 dugongs sighted); ns = not surveyed; zzt = zig zag transect (transect was flown in zig zag pattern across the depth gradient); [#] mean estimate is between 499 and 549 see Preen and Marsh (1995)

Appendix Table 7: Estimates of dugong numbers (+ SE) for each survey block in the southern Great Barrier Reef Region for various surveys conducted between 1986-2011 inclusive. The block locations are in Appendix Figures 3-10. Historical data from Marsh and Saalfeld (1990a and b); Marsh et al, (1996) and (2004); Marsh and Lawler (2000) and (2007).

	Marsh and Sinclair (1989)						Pollock et al. (2006)	
Southern Great Barrier Reef Region								
Block	1986	1992	1994	1999	2005	2011	2005	2011
S1	tfe	122	0	0	zzt	tfe	zzt	tfe
		(71)						
S2	0	94	0	0	tfe	0	tfe	0
		(50)						
S3	301	91	104	55	183	tfe	116	tfe
	(95)	(60)	(56)	(37)	(66)		(64)	
S4	51	tfe	67	0	zzt	dd	zzt	dd
	(48)		(44)					
S5	765	566	406	628	1033	101	898	254
	(161)	(185)	(78)	(162)	(101)	(35)	(295)	(124)
S6	542	tfe	82	dd	dd	dd	dd	dd
	(293)		(60)					
S6A	dd	dd	dd	0	tfe	dd	tfe	dd
S6B	dd	dd	dd	0	zzt	dd	zzt	dd
S6C	dd	dd	dd	tfe	ns	dd	ns	dd
S7	0	0	0	0	zzt	0	zzt	0
S8	240	tfe	38	69	tfe	tfe	tfe	tfe
	(104)		(37)	(63)				
Block	1987	1992	1994	1999	2005	2011	2005	2011
C1	31	70	0	90	tfe	tfe	tfe	tfe
	(35)	(59)		(57)				
C2	65	0	0	n/s	ns	dd	ns	dd
	(69)							
C3	0	35	tfe	353	tfe	tfe	tfe	tfe
		(27)		(211)				
C4	173	40	tfe	445	234	tfe	145	tfe
	(77)	(24)		(236)	(79)		(86)	
C5	312	0	tfe	203	ns	dd	ns	dd
	(122)			(90)				
C6	171	91	tfe	tfe	494	124	331	80
	(87)	(46)			(175)	(23)	(190)	(68)
C7	136	58	54	270	tfe	tfe	tfe	tfe
	(120)	(50)	(38)	(96)				
C8	360	106	183	361	211	tfe	216	tfe
	(92)	(56)	(29)	(157)	(84)		(129)	
C9	0	257	157	424	zzt	tfe	zzt	tfe
		(105)	(77)	(159)				
C10	184	141	377	748	322	144	280	168
	(110)	(89)	(154)	(432)	(118)	(8)	(130)	(132)
C11*	100	86	107	213	103	112	73	106
	(71)	(72)	(71)	(118)	(34)	(4)	(50)	(88)
C12	tfe	tfe	tfe	tfe	zzt	tfe	zzt	tfe
Total all blocks	**3434**	**1757**	**1575**	**3911**	**2580**	**481**	**2059**	**608**
	(456)	**(286)**	**(233)**	**(637)**	**(271)**	**(43)**	**(413)**	**(213)**
Total 2011 blocks only	**3431**	**884**	**890**	**1589**	**1952**	**481**	**1582**	**608**
	(456)	**(222)**	**(187)**	**(476)**	**(236)**	**(43)**	**(379)**	**(213)**

tfe = too few to estimate (<5 dugongs sighted); ns = not surveyed; dd = different design; zzt = zig zag transect (transect was flown in zig zag pattern across the depth gradient); * Block C11 was larger in 2011 than in previous surveys