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An assessment of the distribution and abundance of dugongs and large in-water turtles in Cleveland Bay and adjacent bays to provide baseline information for the Port of Townsville Channel Upgrade Project

A Report for the Port of Townsville Limited

Report No. 2020/ 05
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Prepared by
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EXECUTIVE SUMMARY

- We conducted standarised aerial surveys of Bowling Green, Cleveland and southern Halifax Bays to assess the distribution and abundance of dugongs and in-water large marine turtles in winter (June) and early summer (November) 2019, prior to the start of the capital dredging for the Port of Townsville Channel Upgrade (CU) project.
- Our objective was to provide baseline information to assist the Port of Townsville Limited in its development of a Marine Megafauna Monitoring Program to monitor the potential impacts to marine megafauna before and during the Project, in the context of external environmental changes, especially extreme weather events.
- Dugongs are seagrass community specialists and there was high concordance between the distribution of dugongs and that of seagrass beds in Cleveland Bay monitored by the James Cook University (JCU) Seagrass Ecology Group (TropWATER).
- Eastern Cleveland Bay and the area between Cape Palleranda and Magnetic Island are the most important dugong habitats in the survey area.
- Comparison of the results of the 2019 surveys with the results of similar surveys conducted by Marsh's team at JCU, as part of their long-term series of regional surveys, confirmed marked inter-annual differences in the estimated dugong population in Cleveland-southern Halifax Bays. These differences reflect temporal variations in the status of seagrass in the region as revealed by the annual surveys conducted by the JCU Seagrass Ecology Group since 2007. The estimate of relative abundance of dugongs in the survey region in November 2019 was ~500 (± se 140).
- The proportion of dugongs classified as calves was within the normal range in November 2019. Any effect of the February 2019 Townsville floods on dugong fecundity and neonatal mortality would be expected to take two years to manifest, so it is too early to be certain if there will be such an effect.
- Cleveland-southern Halifax Bays are also important habitats for large juvenile adult turtles, which could not be reliably identified to species during the aerial surveys. The estimate of relative abundance of large turtles in the survey region in November 2019 was ~12,000 (±4000).
- The reasons for the difference between surveys in the number of turtles sighted is unknown, especially the large number seen in November compared with June 2019.
- The Cleveland–southern Halifax Bay region is one of the most important dugong areas in the Great Barrier Reef region south of Cape York. Nonetheless, the direct overlap of the CU bund wall and dredging with the major dugong and large juvenile and adult marine turtle habitats in Cleveland–southern Halifax Bays is low. The biggest risk of the CU project to both dugongs and turtles will be from vessel strike, which can be reduced by limiting vessel speed.
- The aerial surveys design used here was developed for regional scale surveys and the precision of the population estimates at a local scale is low. As a result, the power to detect significant change in the size of a local population is extremely limited. Aerial surveys such as described in this report are not suitable for monitoring the local scale impacts of developments such as the CU project, especially when the impact of a development is confounded with external environmental influences such as extreme weather events.
- Detecting the local-scale impacts of a development on dugongs and large turtles in a construction timeframe is likely to be impossible, unless the impact of the development on the animals is catastrophic. Consequently, it would be more useful for the Port Authority of Townsville to fund research on marine megafauna and proxy studies on water quality and seagrass rather than to attempt to monitor the direct impacts of the CU project on megafauna. Such studies have the potential to inform management of long-term impacts on the megafauna in the face of extreme weather events.

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1. INTRODUCTION

The port of Townsville is operated by the Port of Townsville Limited, which is undertaking the Channel Upgrade (CU) project to enable the Port to accommodate ships of up to 300 meters in length (https://www.townsville-port.com.au/infrastructure/infrastructure-projects/channel-upgrade/). The CU project involves widening of the shipping channel and construction of a rock wall that will protect a 62-ha reclamation area that will eventually accommodate expanded Port infrastructure.

The Port of Townsville is developing a Marine Megafauna Monitoring Program to monitor potential impacts from the Channel Upgrade project on marine megafauna including marine turtles and dugongs.

Since the 1980s, large-scale aerial surveys using the standardised techniques developed by Marsh and Sinclair (1989) have provided much of the information used to inform the management of dugongs in Australia. The objective of these surveys has been to provide an assessment of the distribution and abundance of dugongs at regional scales and a time series for temporal comparisons. Surveys of the Townsville region have been conducted as part of the southern Great Barrier Reef regional surveys since the 1980s (see Appendix Figure 1). The surveys established that Cleveland Bay near Townsville is one of the three most important habitats for dugongs in the Great Barrier Reef Region, south of Cape York (Marsh 2000, Marsh et al. 2011).

The Marsh and Sinclair survey technique was improved by Pollock et al. (2006) and Hagihara et al. (2018) to account for the spatial heterogeneity in availability bias (animals that are not available to observers because of water turbidity). The extra field data required for these new techniques have been collected only since 2000. The surveys have also provided information on the distribution and relative abundance of large juvenile and adult in-water turtles.

The results of these surveys suggest considerable temporal variability in the size and/or distribution of the dugong population of most survey regions. This variability is likely to be the cumulative effect of several confounded factors including dugong mortality (Meager and Limpus 2014) and movements resulting from temporal and spatial changes in the distribution of their seagrass food (Marsh et al. 2011, Sobtzick et al. 2017) due to extreme weather events. Satelitte tracking (Marsh and Rathbun 1989, Sheppard et al. 2006, Gredzens et al. 2014, Cleguer et al. 2015) has also confirmed the movements of dugongs between bays in the Great Barrier Reef region.

There is a risk that extreme weather events will cause seagrass dieback in Cleveland Bay during the CU project with consequential changes in the distribution, abundance and mortality of dugongs and large juvenile and adult in-water turtles (Sobtzick et al. 2012, 2017; Meager and Limpus 2014).

The objective of this report is to provide:

(1) An assessment of the distribution and abundance of dugongs and in-water large juvenile and adult turtles in Bowling Green and Cleveland-southern Halifax Bays in winter (June) and early summer (November) 2019, prior to the start of the capital dredging for the Channel Upgrade (CU) project in the context of:

> (a) JCU's time series of regional surveys, and
>
> (b) The information on the status of seagrasses in the survey region obtained by the JCU Seagrass Ecology Group, and

(2) Baseline information to assist the Port of Townsville Limited in its development of a Marine Megafauna Monitoring Program to monitor the potential impacts to marine megafauna before and during the CU Project.

2. METHODOLOGY

2.1 Survey design

The design for the aerial survey was based on that used in previous aerial surveys of Bowling Green (Block C7) and Cleveland and southern Halifax Bays (Block C8) conducted by JCU researchers (Appendix 1). The orientation and spacing of transects flown in June and November 2019 are shown in Appendix 2. Each survey team consisted of four trained observers and an experienced team leader.

2.2 Survey methodology

The aerial survey methodology followed the strip transect aerial survey technique detailed in Marsh and Sinclair (1989) and used in earlier large-scale surveys in the Great Barrier Reef region (*e.g.*, Sobtzick et al. 2017). A 6-seat, high-wing, twin-engine Partenavia 68C was flown along predetermined transects as close as possible to a ground speed of 100 knots. The survey was conducted at a height of 500 feet (152 m) above sea level and at a sampling intensity of ~20% (Appendix 3)

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

Dugongs were the main focus of these surveys, followed by marine turtles. Dolphins and other marine megafauna such as sharks, rays and sea snakes were also recorded. However, as observers were asked to prioritise dugong and turtle sightings it is likely that these other marine animals were underreported and therefore the data are not included here. For each animal sighting, observers recorded the type of animal (*e.g.*, dugong or turtle), total number of animals seen, position in the transect (*e.g.,* low or medium), and water visibility (see Appendix 4 for environmental conditions). In addition, the number of calves was recorded for each marine mammal sighting. Calves were defined as being less than 2/3 of the size of the cow and swimming in close proximity to her. For the calculation of the Perception Correction Factor, cow and calf pairs were counted as one unit as calves are not independent from cows.

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

The survey leader collected data on environmental conditions (Appendix 4) at the beginning of each flight (cloud cover, cloud height, wind speed and direction, and air visibility) and each transect (cloud cover). Every few minutes during each transect, and whenever conditions changed, the survey leader recorded sea state, visibility, and glare on each side of the aircraft (assessed by the mid-seat observers).

2.3 Population and density estimates

2.3.1 Dugong population estimates

Dugong relative abundance was estimated using the Hagihara method (Hagihara et al. 2018) which corrects for availability bias (dugongs not available to observers because of environmental conditions and depth-corrected diving behavior) and perception bias (animals visible in the survey transect but missed by observers). Dugong sightings for the June 2019 survey were combined with those from blocks flown in the northern Great Barrier Reef survey (during the same period) in order to increase the precision of the perception bias estimate. A similar procedure was followed for the November data.

2.3.2 Turtle population estimates

Population estimates for all large juvenile and adult marine turtles (not identified to species) were calculated using the Fuentes et al. (2015) methodology, which uses published data on green turtle diving to calculate the availability bias correction factor. The methodology used to correct the turtle perception correction factors was similar to that used for dugongs.

2.4 Spatial modelling

Following Sobtzick et al. (2017) we developed spatially-explicit models of dugong and marine turtle density and distribution. The input data were: (a) the dugong counts corrected for perception bias and depth-specific availability bias as per Hagihara et al. (2018); (b) uncorrected marine turtle counts. The data were modelled using the geostatistical interpolation method *Empirical Bayesian Kriging* (EBK) in ArcGIS 10.7. EBK creates multiple simulations of the semivariogram by sequentially changing input parameters (e.g. model fitted) to find the best fit parameters for the input data. The smoothed search neighbourhood for the dugong data was a radius of 3700 m, and for the turtle data 2000 m. Relative densities were calculated at a grid size of 1km^2 for both species. For dugongs, grid cells were classified into four categories based on the relative density of dugongs estimated from the spatially explicit population models and the frequency analysis of Grech and Marsh (2007) and Grech et al. (2011): Very High (>1 dugongs per km^2), High (0.5-1 dugongs per km^2), Medium (0-5 dugongs/turtles per km^2) and Low (0 dugongs per km^2). The classification for large juvenile and adult turtles included three categories: High ($\geq$0.5 turtles per km^2), Medium (0-5 turtles per km^2) and Low (0 turtles per km^2)

3. RESULTS

3.1 Survey flight summary

The winter survey was conducted on June 13 and 14 2019; the summer survey on November 5 and 6 2019.

3.2 Conditions

In both June and November, sea state was slightly higher in Bowling Green Bay (Block C7) than in Cleveland-southern Halifax Bays (Block C8), while glare (means of the modes) was lower in Block C7 than in Block C8 (Appendix 5).

3.3 Observations

The data included in this report include dugong and marine turtle sightings that occurred on transect. The locations of each sighting are displayed in Appendix 2.

3.3.1 Dugong sightings

In June 2019, 13 dugongs were sighted on transect in Bowling Green Bay (Block C7) and 29 in Cleveland and southern Halifax Bays (Block C8; Appendix 2). The corresponding numbers in November 2019 were nine dugongs sighted in Block C7 and 32 in Block C8 (Appendix 2). The overall proportion of dugongs classified as calves was 4.75% in June and 12.2% (including a set of twins) in November.

3.3.2 Sightings of large juvenile and adult marine turtles

In June 2019, 15 turtles were sighted on transect in Block C7and 27 in Block C8 (Appendix 2). The corresponding numbers in November 2019 were 16 turtles in Block C7 and 88 in Block C8.

3.4 Population estimates and trends

3.4.1 Dugong population estimates

The probability of observers sighting dugongs that were available for detection was high during both surveys. The perception probability estimates, based on the generalised Lincoln-Petersen models fitted using program MARK (White and Burnham 1999), suggest that the double-observer teams sighted 92 – 94% of the dugongs that were available during both survey periods (Table 1).

Table 1: Details of models used to calculate the perception bias and the perception probabilities for dugongs for each survey.

Month[1]	Model[2]	Probability Estimates (± se)[3]	Perception probability for each tandem team
June	Primary/secondary observers different	Both primary 0.68 (±0.044) Both secondary 0.75 (±0.043)	Port 0.92 Starboard 0.92
November	All observers same	All observers 0.75 (±0.022)	Port 0.94 Starboard 0.94

[1] The observing teams in June and November differed by a single person (see Acknowledgments).
[2] Dugong sightings from the POTL survey area were combined with other sightings from the northern Great Barrier Reef from each respective survey period (See Section 2.3.1). The models are generalised Lincoln-Petersen models of best fit according to Akaike's Information Criterion using the MARK program (White and Burnham 1999), where the perception probability was either the same for all observers, varied according to experience (primary or secondary observers), varied according to side of the aircraft (port or starboard), or was different for every observer.
[3] Probability estimate provided by the model

3.4.1.1 Dugongs in the Survey Area

In June 2019, the dugong population estimate for the survey area was 384 ± se 184 dugongs using the Hagihara method (Table 2). The corresponding estimate for November was 514 ± se 141 dugongs. Dugong numbers were much higher in Block C8 (Cleveland–southern Halifax Bays) than in Block C7 (Cape Bowling Green Bay) (Table 2) for both surveys.

Table 2: Relative dugong abundance (± standard errors) in the survey area based on the Hagihara method.

Block	June	November
Bowling Bay (C7)	83 (± 56)	46 (± 36)
Cleveland-southern Halifax Bays (C8)	301 (± 175)	468 (± 136)
Total all blocks	**384 (± 184)**	**514 (± 141)**

3.4.2 Turtle population estimates

The probability of observers sighting adult and large juvenile turtles that were available for detection was high during both surveys. The perception probability estimates, based on the generalised Lincoln-Petersen models fitted using program MARK, suggest that the double-observer teams sighted 91 – 93% of the adult and large juvenile turtles (of all species) that were available during both survey periods (Table 3).

Table 3: Details of models used to calculate the perception bias and the resultant perception probabilities for large juvenile and adult turtles for each survey.

Month[1]	Model[2]	Probability Estimates (± se)[3]	Perception probability for each tandem team
June	All observers different	Port front 0.73 (± 0.013) Port rear 0.67 (± 0.013) Starboard front 0.63 (± 0.013) Starboard rear 0.78 (± 0.013)	Port 0.91 Starboard 0.92
November	All observers different	Port front 0.72 (± 0.017) Port rear 0.68 (± 0.017) Starboard front 0.73 (± 0.016) Starboard rear 0.74 (± 0.016)	Port 0.91 Starboard 0.93

[1] The observing teams in June and November differed by a single person each time. For the makeup of each team see Acknowledgements.
[2] Turtle sightings from the POTL survey area were combined with other sightings from the northern Great Barrier Reef from each respective survey period (See Section 2.3.2). These models are generalised Lincoln-Petersen models of best fit according to Akaike's Information Criterion using the MARK program (White and Burnham 1999), where the perception probability was either the same for all observers, varied according to experience (primary or secondary observers), varied according to side of the aircraft (port or starboard), or was different for every observer.
[3] Probability estimate provided by the model

3.4.2.1 Turtles in the Survey Area

In June 2019, the population estimate for adults and large juvenile marine turtles in the survey area was 5238 ± se 1805 (Table 4). In November the corresponding population estimate was 12268 (± se 4157) adults and large juvenile marine turtles. Turtle numbers were higher in Block C8 (Cleveland–southern Halifax Bays) than in Block C7 (Cape Bowling Green Bay) (Table 4), especially in November.

Table 4: Relative abundance (± standard errors) of adult and large juvenile marine turtles in the survey area based on the Fuentes method.

Block	June	November
Bowling Green Bay (Block C7)	1974 (± 1400)	1964 (± 1392)
Cleveland-southern Halifax Bays (C8)	3264 (± 1140)	10304 (± 4297)
Total all blocks	5238 (±1805)	12268 (± 4157)

3.5 Spatial modelling

The spatially-explicit model of dugong distribution and density in the survey area demonstrates that the highest dugong densities are in eastern Cleveland Bay and the Cape Pallarenda area (Figure 1). South-east Cleveland Bay was also a hot-spot for large juvenile and adult turtles. However, turtles were more widely distributed especially between Cape Pallarenda and Magnetic Island (Figure 2).

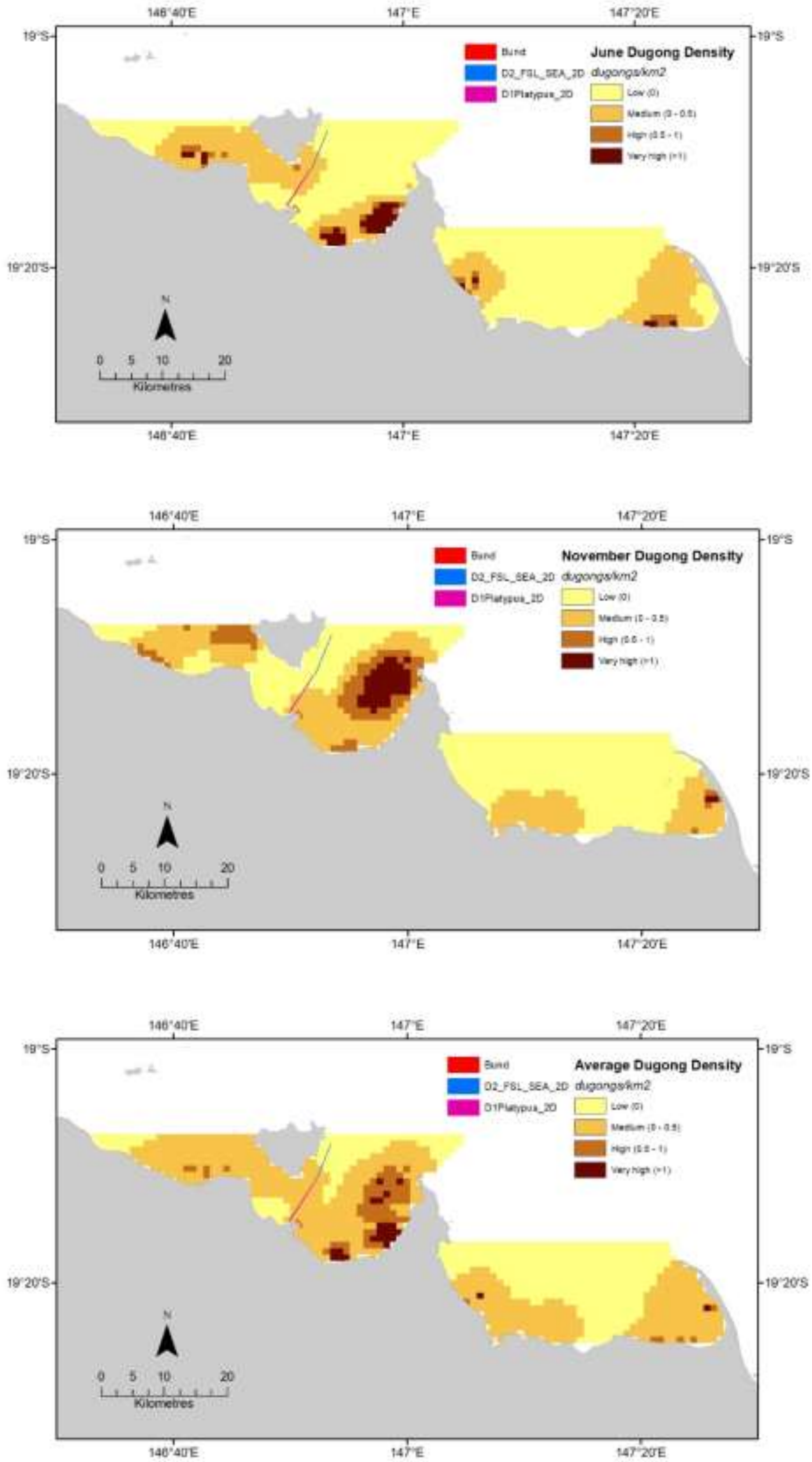


Figure 1: Spatially-explicit models of relative dugong density in Bowling Green, Cleveland and southern Halifax Bays using the bias-corrected 2019 aerial survey data (June top, November middle and average bottom.) Density estimates were generated using the Hagihara method. The lines show the positions of the bund wall to be constructed and the extent of the dredging during the Channel widening project.

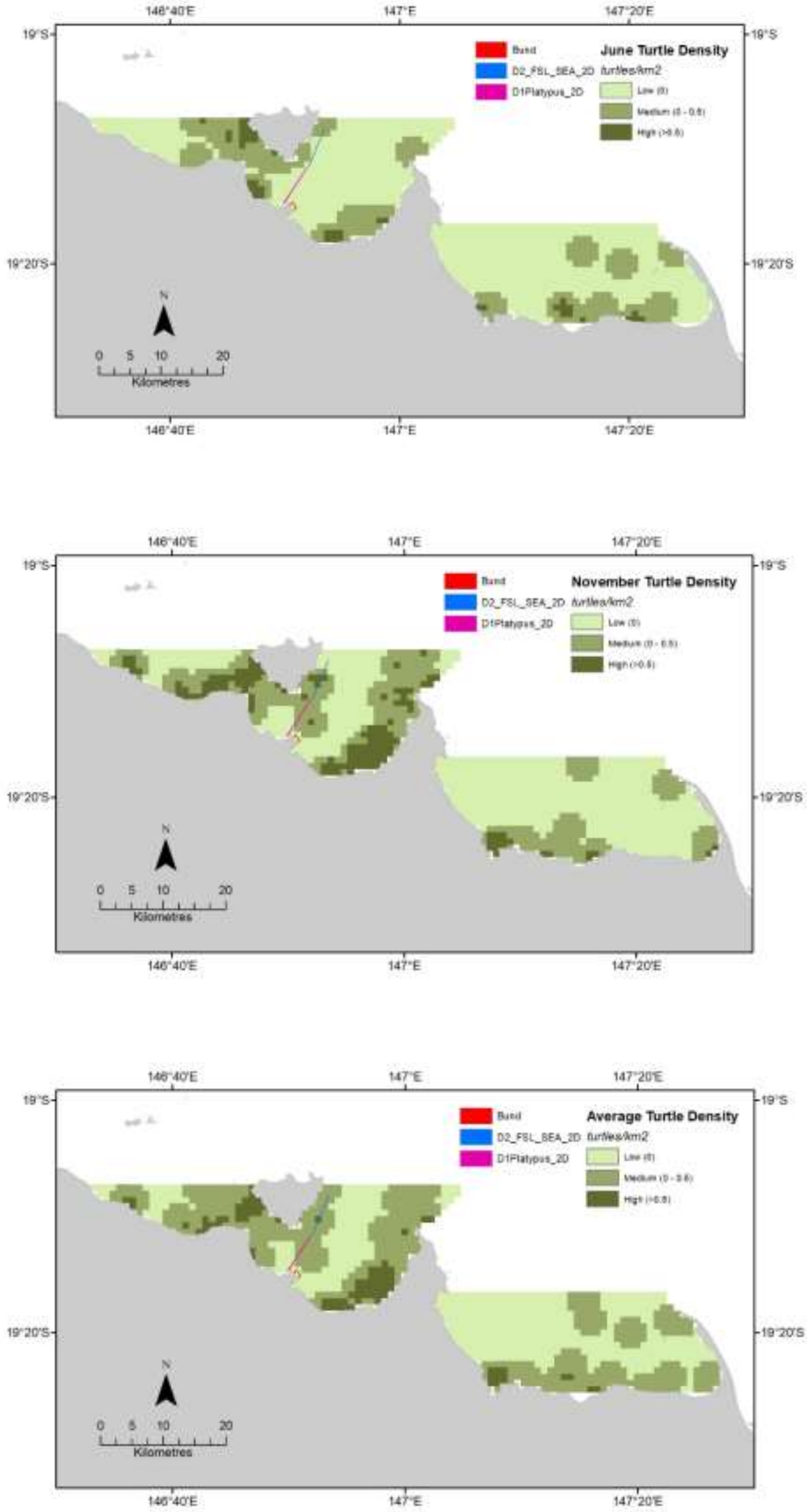


Figure 2: Spatially-explicit models of relative turtle density in Bowling Green, Cleveland and southern Halifax Bays using the 2019 uncorrected aerial survey data (June top; November middle and average bottom). The lines show the positions of the bund wall to be constructed and the extent of the dredging during the Channel widening project.

4. DISCUSSION

4.1 Overview of results in the context of information on the seagrass communities

The dugong (*Dugong dugon*) and the six species of marine turtles that occur in Australia are all listed as Matters of National Environmental Significance and are all in the top 30 migratory species that trigger the *EPBC Act* in the consideration of development proposals in Australia (Jason Ferris DAWE pers comm to Marsh 2019).

The results of the 2019 surveys reported here confirm the importance of Cleveland-southern Halifax Bays as regionally important habitat for dugongs. The regional-scale surveys conducted by the JCU group since the 1980s (Marsh and Saalfeld 1990; Marsh et al., 1996; Marsh and Lawler 2000, 2007; Sobtzick et al. 2017) have consistently found the Townsville region to be one of the three most important dugong areas in the Great Barrier Reef World Heritage area south of Cape York (Marsh 2000).

Dugongs are seagrass community specialists (Marsh et al. 2011). Thus, the high level of concordance between the distribution of dugongs and that of seagrass beds in Cleveland Bay monitored by the JCU Seagrass Ecology Group (*e.g.*, Bryant et al. 2019; McKenna et al. 2019) was as expected. Eastern Cleveland Bay and the area between Cape Palleranda and Magnetic Island are the most important dugong habitats in the survey area. Bowling Green Bay (Block C7) is much less important, although dugongs have been seen there on some surveys, including both surveys in 2019.

The time-series of aerial surveys conducted by JCU have found marked inter-annual differences in the estimated dugong population in Cleveland-southern Halifax Bays (Block C8; Table 5). These differences reflect temporal differences in the status of seagrass in the region as revealed by the annual surveys conducted by the JCU Seagrass Ecology Group since 2007 (*e.g.*, Bryant et al. 2019; McKenna et al. 2019). For example, in 2011 when the seagrass in Cleveland Bay was in very poor condition following the weather-driven declines between 2009-2011 (see Bryant et al. 2019) only one dugong was sighted in Block 8 (Sobtzick et al. 2012), too few to estimate the population size. Whereas in 2016, when the seagrass condition was categorised as good (see Bryant et al. 2019) the estimated population was 1171 $\pm$ se 423 dugongs. Recent seagrass surveys provide some evidence of a lag effect from the February 2019 floods, with seagrass meadow condition not as good in October 2019 as in 2016 (McKenna et al. 2019). In October 2019 the coastal seagrass meadows covered some 10,499 + 1,167 ha, a 19% increase in their footprint since May 2019, and a deepwater seagrass meadow was recorded in the area for the first time since 2008 (McKenna et al. 2019). Dugong calf counts (an index of fecundity and neonatal mortality) were within the normal range in November 2019. However, a post-flood lag effect would be expected to take two years to manifest (Fuentes et al. 2016) so it is too early to determine whether the February 2019 flood affected dugong fecundity.

Adult dugongs are estimated to consume about 7% of their body weight in seagrass per day; juveniles ~14% (Marsh et al. 2011). The long-term differences between surveys in estimated dugong relative abundance in the survey area (Table 2) almost certainly reflect their temporary immigration along the coast in search of food. However, the destinations and directions of such movements cannot be confirmed because of the restricted range of the 2019 surveys. Several satellite-tracked dugongs tagged in Cleveland Bay have been recorded in other bays both north and south of Cleveland Bay (Marsh and Rathbun 1989; Sheppard at al. 2006). However, the technology available at the time of these studies did not enable the dugongs to be tracked while they were moving between bays, so their travel routes are unknown. Such movements have been shown to be highly individualistic (Sheppard at al. 2006).

Table 5: Time series of standardised aerial survey population estimates of dugongs and large juvenile and adult in-water turtles in Bowling Green Bay (Block C7) and Cleveland-southern Halifax Bays (Block C8). All the results reported here are from surveys conducted at the same time of year (late dry season). Data are reproduced from Sobtzick et al. (2012) and Marsh et al. (2018).

	2005	2011	2016	2019
Dugongs				
Bowling Green Bay (Block C7)	Tfs	tfs	tfs	46 ± se 36
Cleveland-southern Halifax Bays (Block C8)	193 ± se 101	tfs	1171 ±se 423	468 ± se 136
Total	**193** ± se **101**	**tfs**	**1171 ± se 423**	**514 ± 141**
Large juvenile and adult turtles				
Bowling Green Bay (Block C7)	998 ± se 933	na	tfs	1964 ±se 1392
Cleveland-southern Halifax Bays (Block C8)	1546 ± se 284	na	5706 ± se 2551	10304 ± se 4297
Total	**2544 ±se 1587**	**na**	**5706 ±se 2551**	**12268 ± se 4157**

tfs= too few seen to calculate a population estimate
na= data not available

The Cleveland-southern Halifax Bay region is also important habitat for large juvenile and adult turtles (Figure 2 and Table 5). These turtles could not be reliably identified to species during the aerial surveys. The reasons for the differences between surveys in the number of turtles sighted is unknown, especially the large number seen in November compared with June 2019 (Table 4). The survey team differed by only one member between June and November, all members were experienced observers and the survey conditions were similar. It is possible that there are seasonal differences in the diving behaviour of turtles which may affect the proportion of the population available to aerial survey observers, however there are no data to test this hypothesis. The major advantage of recording turtles is to enable the spatial modelling of their habitat (Figure 2).

4.2 Implications for the Port Authority of Townsville

There are two important messages from this study regarding the evaluation of any effects of the CU project on dugongs and large in-water turtles. The first is that, the direct overlap of the CU bund wall and dredging and the most important dugong (Marsh 2000) and large juvenile and adult marine turtle habitats in Cleveland–southern Halifax Bays is low (Figures 1 and 2). The biggest risk of the CU project to both dugongs and turtles will be from vessel strike, which can be reduced by limiting vessel speed (Hazel et al. 2007; Hodgson and Marsh 2007).

The second is the statistical difficulty of detecting a significant impact. It is notoriously difficult to determine the trend in a marine mammal population (Taylor et al. 2007) unless there is a precipitous decline. The aerial survey design used here was developed for regional scale surveys, and the precision of the population estimates at the local scale surveyed in 2019 is consequently low (Tables 2, 4 and 5). As a result, the power to detect significant change in the local size of the population is extremely limited. Prospective Bayesian power analysis of longitudinal data from the entire inshore Great Barrier Reef region indicates that these problems are very difficult to overcome, even with more intense and more frequent sampling (Marsh et al. 2018). Aerial surveys are not suitable for detecting the local scale impacts of developments on the animals, especially when the impact of a development is confounded with external environmental influences such as extreme weather events. Detecting the local-scale impacts of a development on dugongs and large turtles in a construction timeframe is likely to be impossible, unless the impact of the development is catastrophic. Consequently, it would be more useful for Port of Townsville Limited to fund proxy studies on water quality and seagrass and relevant megafauna research and, rather than to attempt to monitor the direct impacts of the CU project on the animals. Such studies have the potential to inform management of long-term impacts on the site, in this case the Port of Townsville, in the face of extreme weather events.

5. REFERENCES

Bryant, C.V., Wells, J.N. and Rasheed, M.A. (2019) Port of Townsville Annual Seagrass Monitoring Survey: October 2018. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 47 pp.

Cleguer, C., Limpus, C.G., Hamann, M., Marsh, H. (2015).Annual report on dugong tracking and habitat use in Gladstone in 2015. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program.

Fuentes, M.M.P.B., Bell, I., Hagihara, R., Hamann, M., Hazel, J., Huth, A., Seminoff, J., Sobtzick, S., Marsh, H. (2015). Improving estimates of in-water marine turtle abundance by adjusting aerial survey counts for perception and availability biases. *Journal of Experimental Marine Biology and Ecology*, 471:77-83.

Fuentes, M. M., Delean, S., Grayson, J., Lavender, S., Logan, M., Marsh, H. (2016). Spatial and temporal variation in the effects of climatic variables on dugong calf production. *PloS one*, 11(6):e0155675.

Grech A. and Marsh H. (2007) Prioritising areas for dugong conservation in a marine protected area using a spatially explicit population model. *Applied GIS*. **3**(2): 1 - 14.

Grech A., Sheppard J., and Marsh H. (2011) Informing species conservation at multiple scales using data collected for marine mammal stock assessments. *PLoS ONE*. **6**(3): e17993.

Gredzens C., Marsh H., Fuentes M. M., Limpus C. J., Shimada T., and Hamann, M. (2014) Satellite tracking of sympatric marine megafauna can inform the biological basis for species co-management. *PloS one*, **9**(6), e98944.

Hagihara, R., Jones, R., Sobtzick, S., Cleguer, C., Garrigue, C., and Marsh. H. (2018). Compensating for geographic variation in detection probability with water depth improves abundance estimates of coastal marine megafauna. PLoS ONE, 13 (1) e0191476. https://doi.org/10.1371/journal.pone.0191476

Hazel J., Lawler I.R., Marsh H.D. and Robson S.K. (2007). Vessel speed increases collision risk for the green turtle *Chelonia mydas*. *Endangered Species Research*, 3: 105 – 113

Hodgson A. and Marsh H.D. (2007). Response of dugongs to boat traffic: The risk of disturbance & displacement. *Journal of Experimental Marine Biology & Ecology* 340: 50 – 61.

Marsh, H. (2000). Evaluating management initiatives aimed at reducing the mortality of dugongs in gill & mesh nets in the Great Barrier Reef World Heritage Area. *Marine Mammal Science*16: 684-94.

Marsh, H., and Lawler, I. (2000). Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: Results of an aerial survey in October-December 1999. Great Barrier Reef Marine Park Authority/James Cook University.

Marsh H., and Lawler I. (2007). Project 2: Dugong distribution and abundance on the urban coast of Queensland: a basis for management. Marine and Tropical Science Research Facility, Interim Projects 2005-06 Final Report.

Marsh, H., and Rathbun, G. B. (1989). Development and application of conventional and satellite radio-tracking techniques for studying dugong movements and habitat usage. *Australian Wildlife Research*, 17(1):83-100.

Marsh, H. and Saalfeld, W.K. (1990). The distribution and abundance of dugongs in the Great Barrier Reef region south of Cape Bedford. *Australian Wildlife Research* 17: 511-24

Marsh H., and Sinclair D. F. (1989) Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *Journal of Wildlife Management* 53(4):1017-1024.

Marsh, H, Corkeron, P., Lawler, I., Preen, A., Lanyon, J. 1996, The status of the dugong in the southern Great Barrier Reef Marine Park. Report to the Great Barrier Reef Marine Park Authority.

Marsh H., O'Shea T. J., and Reynolds J.R. (2011) The ecology and conservation of Sirenia; dugongs and manatees. Cambridge University Press, 521pp.

Marsh, H, Hagihara R, Hodgson A, Rankin R, and Sobtzick, S. (2018). Monitoring dugongs within the Reef 2050 Integrated Monitoring and Reporting Program. Final report of the dugong team in the megafauna expert group, July 2018. Great Barrier Reef Marine Park Authority.

McKenna, S.A., Van De Wetering, C., Rasheed. M.A. and Well. J.N. (2019), Port of Townsville Seagrass Monitoring Program, Brief Report: September/October 2019,. James Cook University Publication, Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), Cairns, 47 pp.

Meager J. J., and Limpus C. (2014), Mortality of inshore marine mammals in eastern Australia is predicted by freshwater discharge and air temperature. *PLoS ONE* **9**(4): e94849

Pollock K., Marsh H., Lawler I., and Alldredge M. (2006) Modelling availability and perception processes for strip and line transects: an application to dugong aerial surveys. *Journal of Wildlife Management* 70: 255-262.

Sheppard J., Preen A. R., Marsh H., Lawler I. R., Whiting S., and Jones R. E. (2006) Movement heterogeneity of dugongs, *Dugong dugon* (Müller) over large spatial scales. *Journal of Experimental Marine Biology & Ecology* **334**: 64–83.

Sobtzick S., Hagihara R., Grech A., 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 the summer of 2010-11, Final Report to the Australian Marine Mammal Centre and the National Environment Research Program June 1 2012

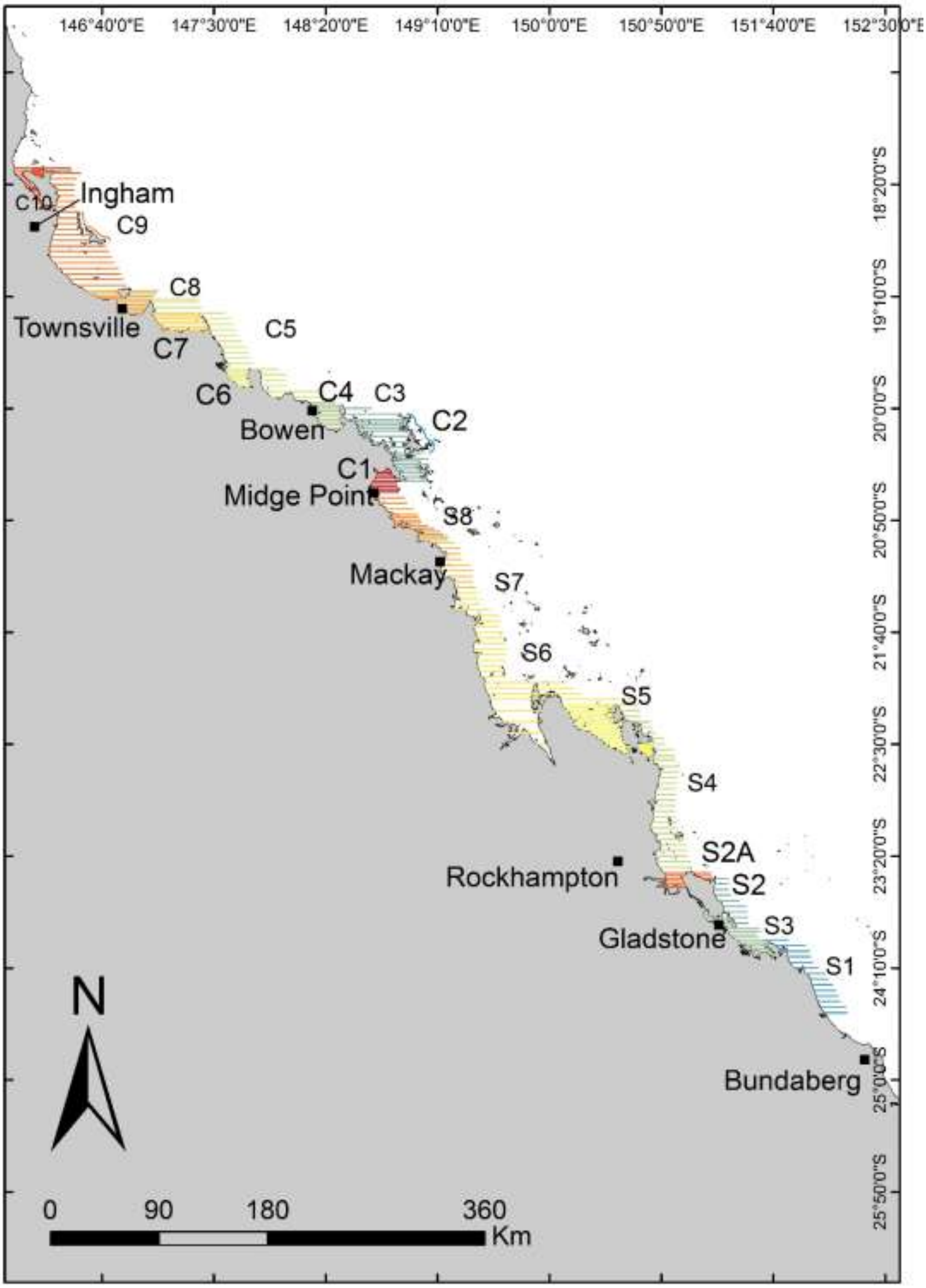
Sobtzick, S., C. Cleguer, R. Hagihara and H. Marsh (2017). Distribution and abundance of dugong and large marine turtles in Moreton Bay, Hervey Bay and the southern Great Barrier Reef. A report to the Great Barrier Reef Marine Park Authority. Townsville, Australia, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 17/21, James Cook University.

Taylor B. L., Matinex M., Gerrodette T., and Barlow J. (2007) Lessons from monitoring trends in abundance of marine mammals. *Marine Mammal Science*, 23: 157-175.

White G.,and Burnham K. P. (1999) Program MARK: survival estimation from populations of marked animals. *Bird Study* **46**: 120-139.

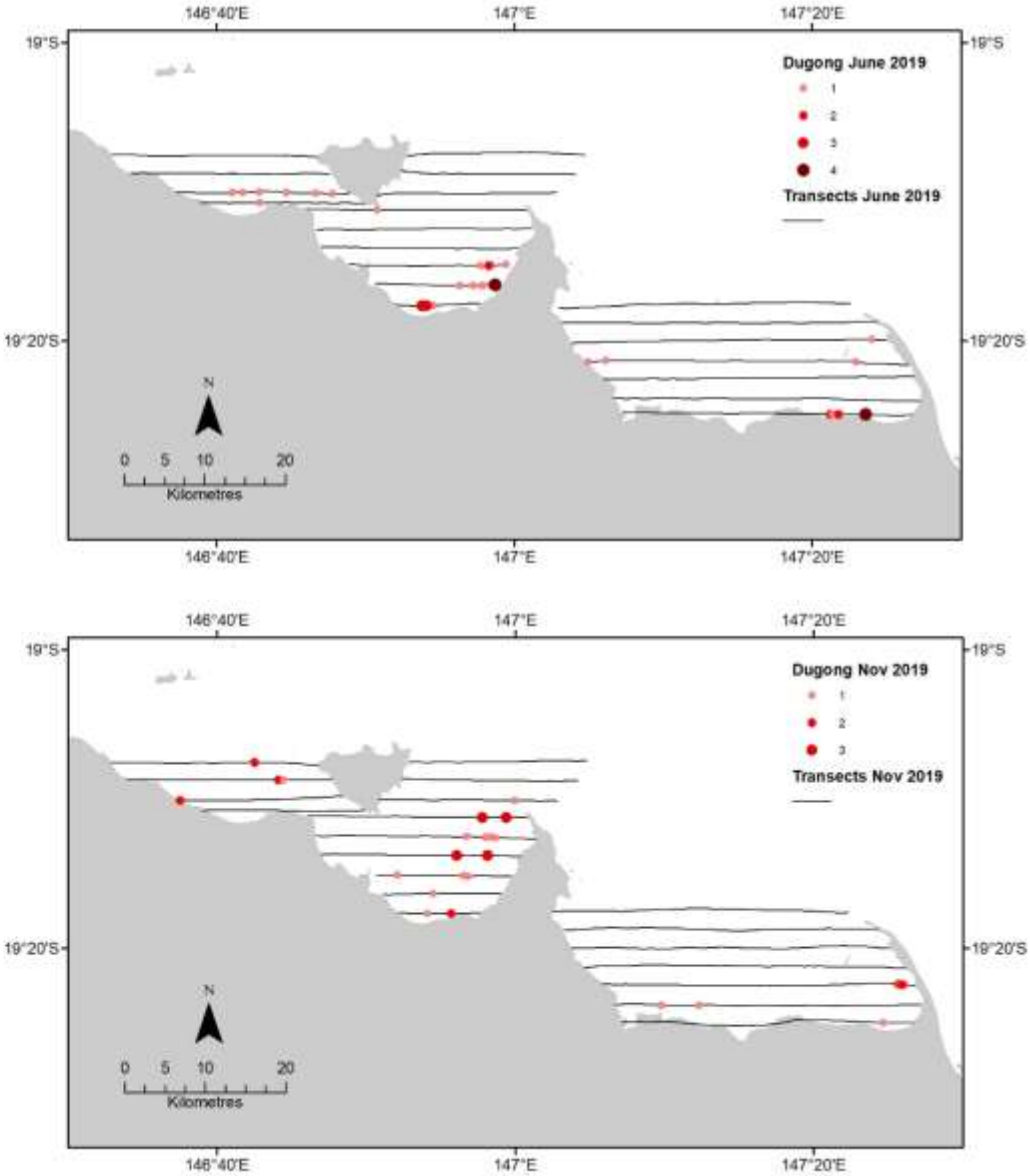
6. APPENDICES

APPENDIX 1: **Regional context for the 2019 aerial surveys.**

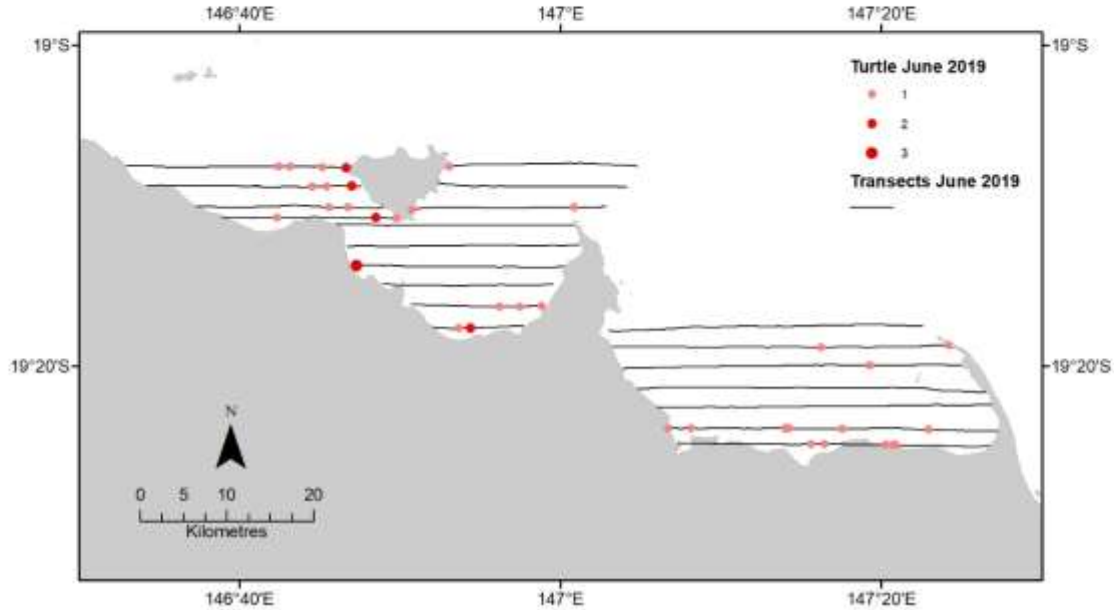


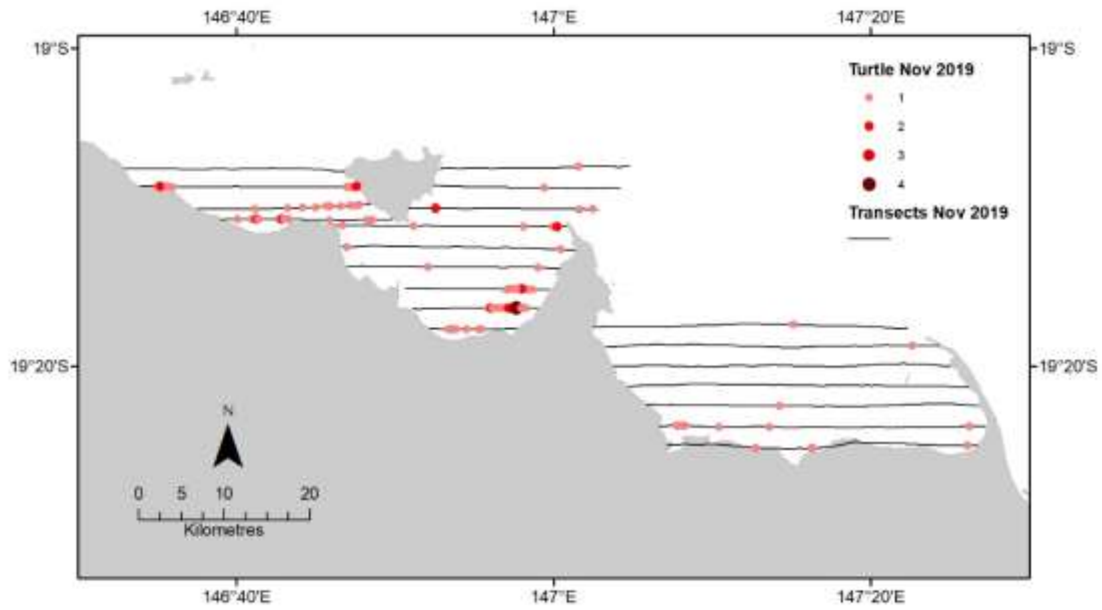
Appendix Figure 1.1 An example of the transects flown during the regional surveys that provide a context for this local survey of Blocks C7 and C8 (reproduced from Sobtzick et al. 2017).

APPENDIX 2: Maps of the survey region showing transects and animal sightings



Appendix Figure 2.1: Distribution of dugong sightings on the aerial survey transects in June (top) and November 2019.





Appendix Figure 2.2: Distribution of sightings of large juvenile and adult turtles on the aerial survey transects in June (top) and November 2019.

APPENDIX 3: Sampling intensity

Appendix Table 3.1: Sampling intensity of the blocks surveyed in June and November 2019.

	June		November	
Block	**Block size (km^2)**	**Sampling Intensity (%)**	**Block size (km^2)**	**Sampling Intensity (%)**
Bowling Green Bay (C7)	581	21.7	581	22.7
Cleveland-southern Halifax Bays (C8)	598	18.4	598	18.2

APPENDIX 4: Scales used to record environmental conditions

Appendix Table 4.1: Scale used to record in-water water visibility from the survey aircraft.

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

Appendix Table 4.2: Scale used to record the effect of glare the surface of the water on the capacity of the observers to see megafauna from the survey aircraft.

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

APPENDIX 5: Weather conditions

Appendix Table 5.1: Weather conditions encountered during 2019 surveys**.**

	Block C7		**Block C8**	
	June	**November**	**June**	**November**
Max Wind Speed (km/h)	<10	0	<10	<10
Cloud Cover (oktas)	5	0	2	3
Min cloud height (ft)	3000	2000	2000	2000
Beaufort Sea State (mean)	2.33	2.49	2.24	1.84
Beaufort Sea State (range)	(2-3)	(1-3)	(1-3)	(1-3)
Glare (means of modes per transect)	0	1	2	1.5
Glare range	(0-3)	(0-3)	(0-3)	(0-3)
Air Visibility (km)	10+	10+	10+	10+