

## Appendix 7. Progress report dugong project 1.2.5 Phase 2/2 June 2016

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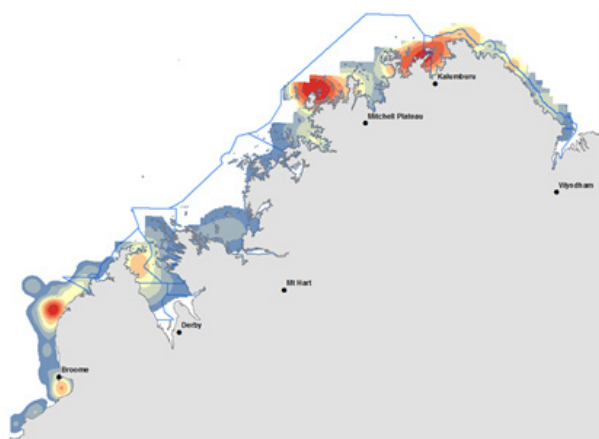
### Project 1.2.5 - Integrating Indigenous knowledge and survey techniques to develop a baseline for dugong (*Dugong dugon*) management in the Kimberley

PETER BAYLISS<sup>1,2</sup>, TJ LAWSON<sup>1,2</sup> AND EMMA WOODWARD<sup>1,2</sup>

<sup>1</sup>CSIRO Oceans & Atmosphere Flagship, Brisbane, Queensland, Australia

<sup>2</sup>Western Australian Marine Science Institution (WAMSI), Perth, Western Australia, Australia

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**Corresponding author and Institution:** Peter Bayliss (CSIRO, Brisbane, Queensland, Australia)

## Milestone Progress Report for Project 1.2.5 Integrating Indigenous knowledge and survey techniques to develop a baseline for dugong (*Dugong dugon*) management in the Kimberley

**Phase 2 Milestone Report No:** 2/2 Submit an annual progress report summarising results to date integrating Indigenous Knowledge of dugongs with scientific data, outlining relevance to future monitoring and management of dugongs in the North Kimberley.

**Milestone Due Date:** 6<sup>th</sup> June 2016

### Summary

This report summarises annual progress for the following three components of the Kimberley dugong project, with focus on the first component: (i) use of aerial survey to provide a baseline of dugong distribution and abundance for future monitoring and management purposes; (ii) understanding movement ecology and habitat use; and (iii) integrating Indigenous Knowledge with scientific data.

The aerial survey of dugongs in the Kimberley was completed in October 2015 and preliminary analyses and results are summarised here. The survey was undertaken in full partnership with the Balanggarra, Wunambal Gaambera, Dambimangari and Bardi Jawi Indigenous ranger groups, and their participation is a major contribution. The Kimberley region was divided into 7 survey blocks for logistical reasons and these comprise convenient reporting units. A comparison of dugong population estimates in the Kimberley with other regions across northern Australia is underway but requires a standardised approach. However, in the interim, our provisional estimate is  $11,839 \pm 1,391$  (11.8% SE) dugongs, a density of  $0.36 \pm 0.04 \text{ km}^{-2}$  over  $\sim 33,000 \text{ km}^2$ . Results are comparable with recent surveys undertaken in the NT (November 2015) Gulf of Carpentaria region (R. Groom pers. comm.) that has similar extensive seagrass habitat in shallow coastal waters. The highest densities of dugongs in the Kimberley ( $0.55 \pm 0.15 \text{ km}^{-2}$  and  $0.69 \pm 0.17 \text{ km}^{-2}$ ) were found in survey blocks with the greatest occurrence of large ( $> 1 \text{ km}^2$ ) seagrass patches associated with larger areas of shallow ( $< 20 \text{ m}$  bathymetry) clear water, encompassing Wunambal Gaambera sea country and the proposed North Kimberley marine park. The distribution and abundance of dugongs in the Kimberley were mapped across a 5 km data grid using GIS Kriging extrapolation and smoothing methods to identify “abundance hotspots”, and includes earlier data obtained by Woodside for the Dampier Peninsula in 2009.

The Landsat-derived seagrass map of the Kimberley (Phase 1 milestone report) was examined in relation to dugong abundance using regression analysis. The seagrass map has an uncertain spectral class of “possible seagrass” throughout most survey blocks that requires extensive field validation, hence results are only preliminary. Nevertheless, there is a strong positive relationship between estimates of dugong abundance and the mean extent of large ( $> 1 \text{ km}^2$ ) seagrass patches in blocks, with the “possible” class of seagrass explaining twice as much variation in observed data ( $R^2 = 94\%$ ,  $n=7$ ,  $P=0.0016$ ).

A Bayesian likelihood model was used to map and identify important areas of dugong in the Kimberley across a 5 km grid, and integrates key knowledge from three main sources: (i) Indigenous Ecological Knowledge; (ii) seagrass extent; and (iii) abundance estimates derived by aerial survey. Further development is underway as the approach facilitates continuous updates with new information (or “priors”), a process that underpins adaptive monitoring and management. Additionally, the Bayesian approach can incorporate uncertainty in data and knowledge and this flexibility is now being examined.

Sighting and distribution maps are presented also for snubfin dolphins, all “other” dolphins combined

(and those identified to species), humpback whales and large, most likely green turtles. Progress on the movement ecology and Indigenous Ecological Knowledge components of the project is reported.

## **I Preliminary analysis of aerial survey data**

### **I.1 Methods**

Standardised aerial survey was used to develop the first systematic baseline of dugong distribution and abundance in the north Kimberley. The approach and stratified survey design is described in detail by Bayliss and Wilcox (2015). Field work was completed in October 2015 in partnership with Kimberley Indigenous rangers after a 5-day training course at Gambimerri ranger station on Wunambal Gaambera country (Bayliss *et al.* 2015).

Aerial survey methodology applied to regional dugong populations across northern Australia are outlined in detail by Bayliss (1986), Marsh and Sinclair (1989a,b), Pollock *et al.* (2006) and Hagihara *et al.* (2014). The survey procedures and equipment used to record data are outlined in detail in the dugong aerial survey training manual prepared by Soltzick *et al.* (2013) from James Cook University.

Not all animals are seen during aerial surveys due to visibility bias, resulting in inaccurate estimates of numbers although they may have high precision (as measured by the standard error). This accuracy error has received considerable attention in marine aerial surveys, particularly for dugongs. The probability of detecting animals during a survey involves two processes (after Marsh and Sinclair 1989a): (i) availability bias, when animals present in the search area are not available for detection; and (ii) perception bias, when some animals potentially visible to observers are missed (Fuentes *et al.* 2015). Correction of inherent visibility biases in observed counts aims to increase both the stability (precision) and accuracy of population estimates to provide greater power to detect change for long-term monitoring purposes. However, there are pros and cons of the different approaches used to estimate dugong abundance and their associated errors that have evolved over time (see Appendix Table A9), and the choice that managers make will ultimately depend on what net benefit for what cost given that aerial surveys are expensive. Whilst we have adopted the most recent availability correction factors developed by Hagihara *et al.* (2014) to adjust counts for the proportion of dugongs missed under the water, a combination of estimation models are examined and assessed in terms of accuracy and precision of estimates.

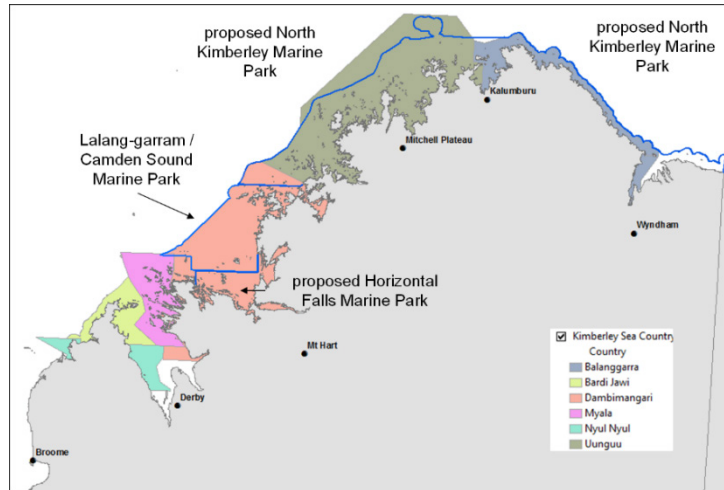
Details on statistical methodology for the treatment of population estimation errors are relegated to Appendices 1-5, allowing the report to focus on spatial methodologies used to identify dugong abundance “hotspots” in relation to jurisdictional boundaries (Fig. 1a. Native Title Sea Country and existing & proposed marine parks), and a proposed Bayesian method to integrate Indigenous Ecological Knowledge with scientific data to better predict important areas for dugongs in the Kimberley.

#### *Survey design*

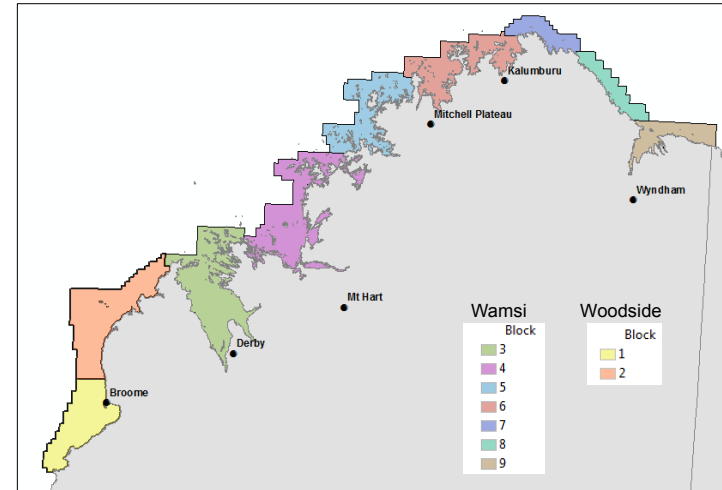
The Kimberley survey area encompasses all coastal waters from the coastline to the 20m bathymetry line, and was arbitrarily divided into 7 survey blocks for logistical reasons (Fig. 1b blocks 3-9; includes the two Woodside Dampier Peninsula aerial survey blocks 1-2, SKM 2009 & RPS 2010). Systematic east-west transects were flown in these blocks based on a pre-stratified survey design (Bayliss & Wilcox 2015; either 5 km or 10 km transect spacing, Fig. 1c). The systematic spacing of transects allowed a 5 km data grid to be projected onto survey blocks for detailed spatial analysis (Fig. 1d).

The area (km<sup>2</sup>) of all over water sample transects 0.4 km wide for each block are summarised in Appendix Table A1 and provides the sampling fraction or intensity (%SI) for population estimation.

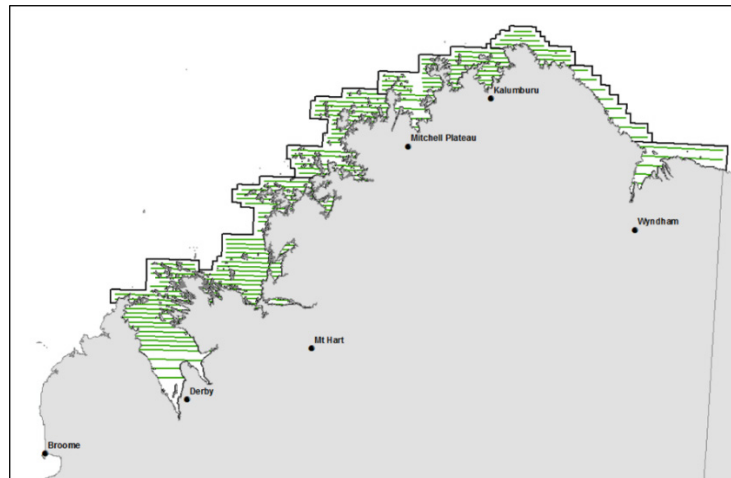
(a)



(b)



(c)



(d)

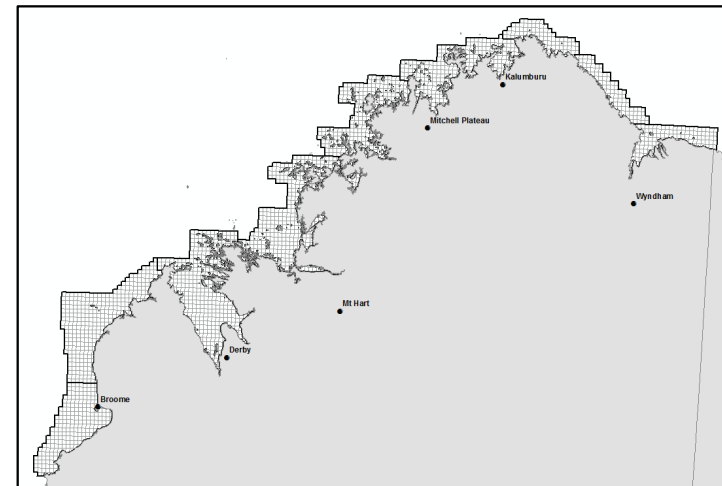


Figure 1a-d. Kimberley boundaries. (a) Native Title boundaries/sea country and proposed and existing WA marine parks. (b) Aerial survey blocks (both the Woodside-Dampier Peninsula 2009 and WAMSI 2015 surveys). (c) Aerial survey transects flown during Sept. - Oct. 2015 with stratified transect design using Indigenous Ecological Knowledge of dugong areas. (d) The 5 km x 5 km aerial survey data grid.

*Distribution and abundance of dugongs in the Kimberley (Sept. – Oct. 2015)***1.2 Results****Population size**

Estimates of dugong population size by survey block and for the entire Kimberley are summarised in Tables 2 and 3 using two different approaches (Models 4 & 5 in Appendix Table A9, respectively). Both approaches are underpinned by the most recent and likely more accurate corrections for availability bias. Although the two methods provide similar results that are not significantly different, the sample errors estimated by Model 5 are considered more robust although higher by a factor of 2 (& nevertheless similar to sample errors produced by previous methodologies; see Appendix Tables A12 & A13).

Table 2. Estimates of population size ( $\hat{N} + SE$ ) and density ( $\hat{D} + SE \text{ km}^{-2}$ ) of dugongs in the Kimberley (Sept. – Oct. 2015) using corrections for availability bias by Hagihara *et al.* (2015) and the Pollock *et al.* (2006) method to estimate perception bias and to derive sample errors (Model 4 in Appendix Table A9).

Block	$\hat{N}$	SE	% SE	$\hat{D}$	SE
3	1,822	126	7	0.23	0.02
4	1,693	147	9	0.22	0.02
5	3,082	289	9	0.58	0.05
6	3,823	402	11	0.72	0.08
7	914	209	23	0.45	0.10
8	623	52	8	0.30	0.02
9	214	53	25	0.08	0.02
<b>Total</b>	<b>12,171</b>	<b>(<math>\pm 576</math>)</b>	<b>4.7</b>	<b>0.37</b>	<b>(<math>\pm 0.02</math>)</b>

Table 3. Estimates of population size ( $\hat{N} \pm SE$ ) and density ( $\hat{D} \pm SE \text{ km}^{-2}$ ) of dugongs in the Kimberley (Sept. – Oct. 2015) using corrections for availability bias by Hagihara *et al.* (2015), the Pollock *et al.* (2006) method to correct for perception bias and the new simulation method to estimate sample errors (Model 5 in Appendix Table A9).

Block	$\hat{N}$	SE	% SE	$\hat{D}$	SE
3	1,758	452	25.7	0.22	0.06
4	2,119	444	21.0	0.28	0.06
5	2,926	792	27.1	0.55	0.15
6	3,682	929	25.2	0.69	0.17
7	636	170	26.7	0.31	0.08
8	541	112	20.7	0.26	0.05
9	177	43	24.0	0.07	0.02
<b>Total</b>	<b>11,839</b>	<b>(<math>\pm 1,391</math>)</b>	<b>11.8</b>	<b>0.36</b>	<b>(<math>\pm 0.04</math>)</b>

The Marsh and Sinclair (1989a) method to adjust for availability bias yields an estimate in the order of 32,000 dugongs in the Kimberley (Appendix Table A11), about 2.7 times higher than the estimate in Table 3. This is not surprising given the difference in detection probabilities (21% available for detection vs. 67-39%) and corresponding correction factor multipliers used (4.79 cf. 1.49 - 2.56). The estimate is only presented here to allow comparison with historical estimates in other regions across northern Australia (e.g. Bayliss and Freeland 1989 for the NT Gulf of Carpentaria/GoC). Estimates of “minimum” population size whereby observed counts are only corrected for perception bias are also presented to allow historical comparisons (e.g. with the NT Top End surveys; results in Appendix Table A10).

### Abundance “hotspots”

The distribution maps of dugongs and other marine wildlife species are illustrated twice, with one map showing the Native Title sea country boundaries and the other the DPaW marine reserve boundaries (i.e. the existing Camden Sound-Lalang-garram marine park & the proposed Horizontal Falls & North Kimberley marine parks).

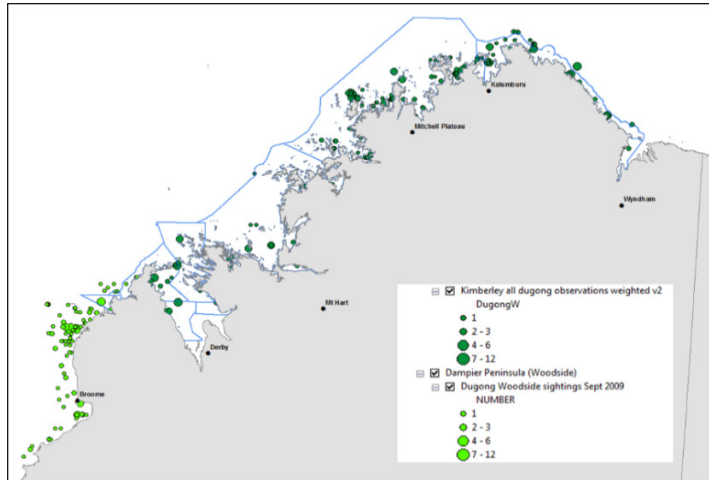
Figure 2a & b illustrates dugong sightings of all observers both on and off transects (n=350 including training sessions). Counts were weighted to standardise for variable observer effort (2 - 4 counters) allowing rear observer data to be used in mapping distributions. Abundance “hotspots” were then mapped in ArcGIS™ using Kernel density smoothing methods (ESRI 2011) applied to all georeferenced weighted observations. The extrapolation of density points was across a high resolution grid (~1.8 km x 1.8 km). The Kernel density smoothing method is analogous to standard Kriging methods that produce similar maps. The September 2009 aerial survey data of dugong distribution along Dampier Peninsula (SKM 2009, PRS 2010) were included also using data supplied by Woodside. Smoothing was undertaken separately for the Woodside and WAMSI survey blocks because data sets were not standardised between them. For example, the Woodside survey used 400 m wide transects/observer (twice that of the WAMSI surveys) and transects were more closely spaced so observed counts appear higher. Hence, any comparison of abundance “hotspots” between the two survey areas would be relative only. Figure 2 (c & d) identifies the abundance “hotspots” for dugongs in Kimberley coastal waters.

Dugong abundance “hotspots” were also mapped by Kernel smoothing across the 5 km aerial survey grid (Fig. 3a & b; numbers per cell are corrected abundance estimates) and shows a similar albeit coarser grain pattern. Only front port and starboard on-transect data used in population analysis were used in this spatial analysis. Extrapolation of density point data at higher resolution than the 5 km data grid does not appear to lead to distortion of overall distribution and abundance patterns.

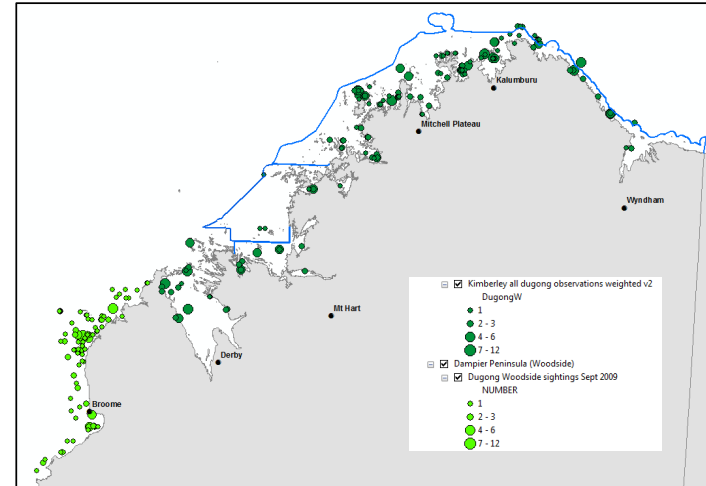
### Proportion of calves

Calves were identified by their small size and close proximity to another, larger animal. About 6% (21/350) of all observed dugongs were calves and these sightings were spread uniformly throughout the survey area. The proportion is about mid-way between those reported elsewhere across northern Australia (3% for the Top End of the NT, Bayliss 1986; ~11% for the NT GoC, Bayliss and Freeland 1989; 13.9% long-term average for the Torres Strait, Marsh *et al.* 2015).

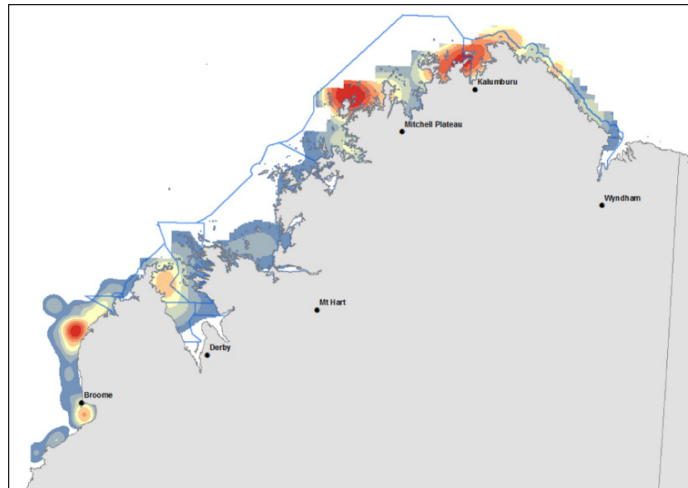
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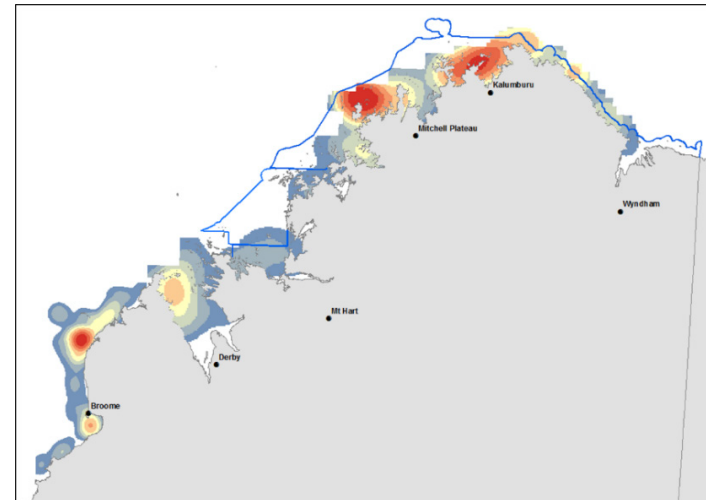


Figure 2 a-d. DUGONG sightings on and off transects in blocks 1-9 for (a) Native Title sea country and (b) proposed and existing marine reserve areas. Relative dugong abundance “hotspots” mapped by Kernel smoothing (extrapolation) of observed data across a high resolution grid (~1.8 km x 1.8 km) for (c) Native Title sea country and (d) proposed and existing marine reserve areas.

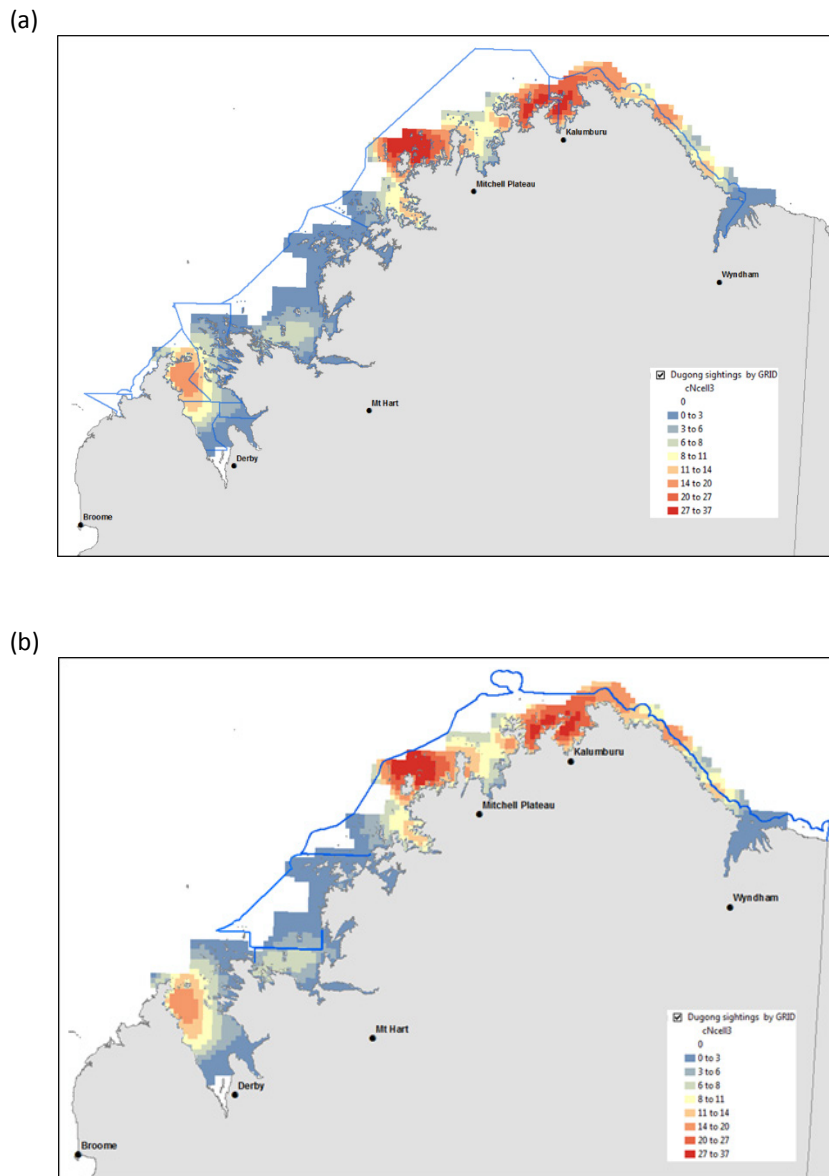
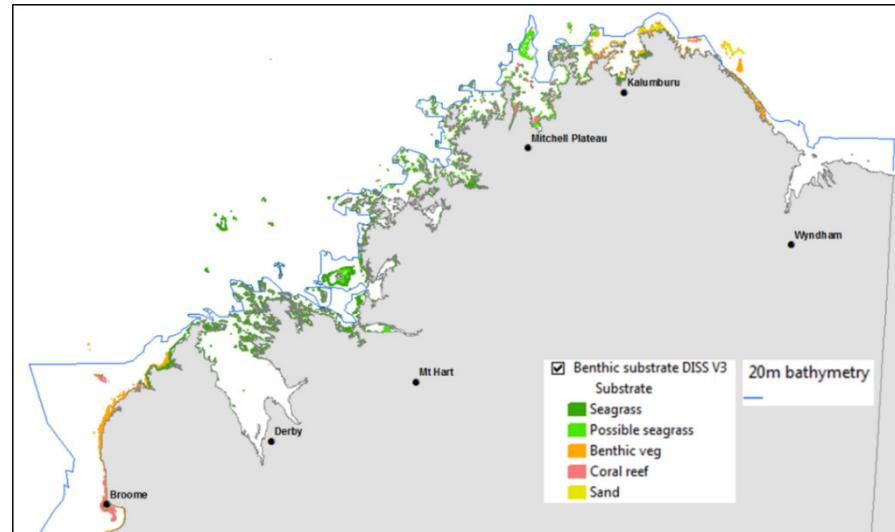


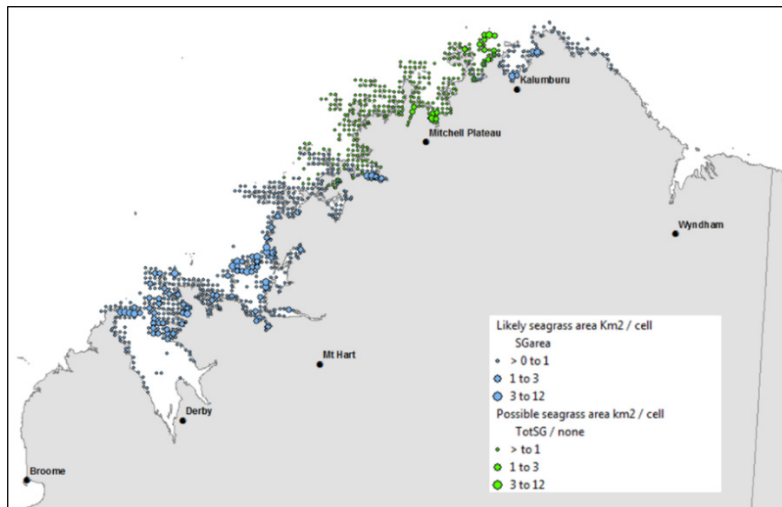
Figure 3 a-b. DUGONG abundance “hotspots” mapped by Kernel smoothing (extrapolation) of weighted sighting data corrected for visibility bias (both perception & availability) across the 5 km aerial survey grid (numbers per cell are corrected abundance estimates) for (a) Native Title sea country and (b) proposed and existing marine reserve areas.

### Dugongs and seagrass

Bayliss and Freeland (1989) found a significant correlation between the extent of seagrass in the NT GoC Carpentaria (map provided by I. Poiner CSIRO pers. comm.) and estimates of dugong numbers by survey block ascertained by broad-scale aerial survey. Hence, the preliminary seagrass map produced by Janet Anstee (CSIRO) from spectral classification of Landsat imagery taken in September 2014 (see Bayliss & Wilcox 2015) was used to assess its predictive ability in explaining broad patterns of dugong distribution and abundance in the Kimberley ascertained by aerial survey in Sept.-Oct. 2015. The Anstee seagrass map has a significant uncertain spectral class of “possible seagrass” throughout blocks 4-9 (Fig. 4a-c) that requires extensive field validation, hence the analyses presented here are preliminary in nature only.



(b)



(c)

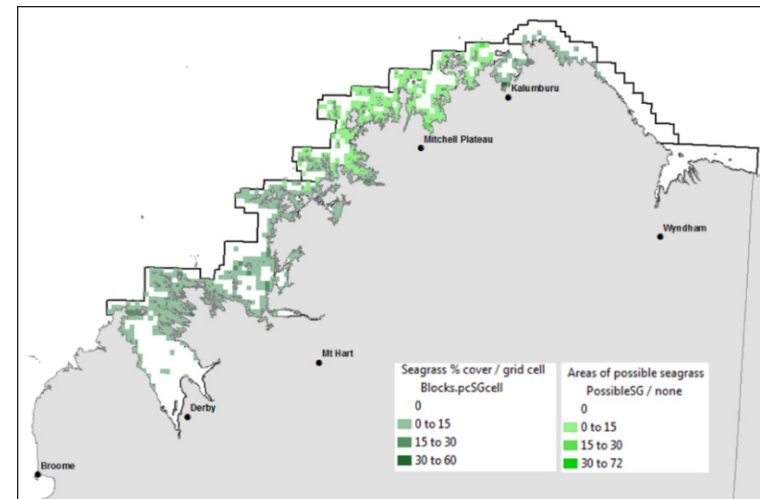


Figure 4 a-d. SEAGRASS. (a) Benthic substrate map of the Kimberley produced from Landsat images (Janet Anstee 2014). Areas mapped as “Seagrass” are likely based on spectral classification and some validation data. Areas marked as “Possible seagrass” require field validation. The 20-m bathymetry line is show. (b) The dispersion of mean Seagrass and Possible seagrass patches/5 km grid cell (mean area of patch/cell  $\text{km}^2$ ). (c) The percentage cover (%) of Seagrass and Possible seagrass / 5 km grid cell.

Multiple partial regression analysis was used to predict estimates of dugongs ( $N_b$ ) from the extent and occurrence of both spectral classes of seagrass in blocks. Given that the fine spatial resolution of the remotely sensed seagrass map data (2-3m pixels) compared to the resolution of blocks (2,030 to 8,055 km<sup>2</sup>) and 5 km survey grids (~ 25 km<sup>2</sup>) within blocks, seagrass data (polygons) were first amalgamated to the size of large patches (>1km<sup>2</sup>). Results show a strong significant positive relationship between estimates of dugong abundance in blocks and the mean extent (km<sup>2</sup>) of large seagrass patches when both spectral classes are combined (Table 4;  $R^2 = 84\%$ ,  $n=7$ ,  $P=0.0022$ ). When seagrass is partitioned into “likely” and “possible” classes the overall relationship is stronger (Table 4;  $R^2 = 94\%$ ,  $n=7$ ,  $P=0.0016$ ), with the possible class of seagrass explaining twice as much variation in the regression model (Table 4; partial regression coefficients 0.79 cf. 0.36 and partial residual plots in Fig. 5a&b).

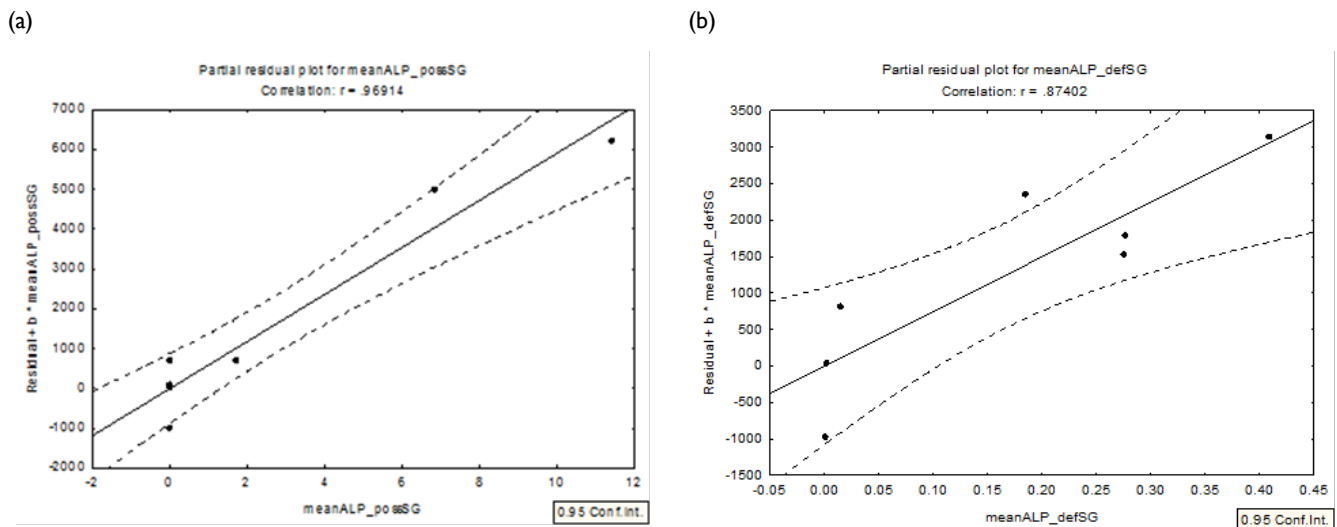


Figure 5 a-b. Partial regression plots between dugong abundance / block ( $N_b$ ) and the mean occurrence and extent of large (> 1km<sup>2</sup>) seagrass patches / block of (a) “possible” and (b) “likely” spectral classes showing a stronger relationship with the possible class.

The abundance of turtles and dugongs in survey blocks is highly correlated (Table 4;  $R^2=86\%$ ,  $n=7$ ,  $P=0.0016$ ), hence their abundance was also examined for trends with seagrass. Results show a significant relationship between estimates of turtle abundance in blocks and the mean extent of large seagrass patches, although not as strong as that for dugongs (Table 4;  $R^2=66\%$ ,  $n=7$ ,  $P=0.017$ ). When seagrass is partitioned into “likely” and “possible” classes in the regression analysis only the possible class was significant and the amount of explained variance increased by 14% (Table 4;  $R^2=72\%$ ,  $P=0.01$ ). Given that turtles also consume macro-algae the “possible” seagrass class is likely to also encompass this benthic substrate type, highlighting the need for future field validation.

Analysis at the resolution of grid cells shows that the mean occurrence and extent (per grid cell / block) of large seagrass patches are more highly correlated to block estimates of both dugong and turtle abundance (dugongs:  $R^2=99\%$ ,  $n=7$ ,  $P<0.001$ ; turtles  $R^2=81\%$ ,  $n=7$ ,  $P=0.004$ ), warranting further investigation using other statistical spatial models such as co-Kriging coupled to Bayesian probability methods (ESRI 2011). That is, spatially correlating extrapolated (smoothed) dugong abundance data from 5 km grids to seagrass data amalgamated to a resolution that explains most variance in dugong abundance. The amount of explained variance is unusually high suggesting the possibility of statistical artefacts in the data (e.g. the large the block size the more grid cells with large seagrass patches) that needs close examination.

Table 4. Summary of the multiple regression analyses between estimates of dugong abundance and seagrass in survey blocks, and similarly for large turtles.

Model	Variable	b*	SE <sub>b</sub> *	b	SE <sub>b</sub>	t	P	adj R <sup>2</sup>	P <sub>reg</sub>	SE <sub>reg</sub>
1. N <sub>b</sub> -dugongs / block	Intercept			1,941	672	2.89	0.034	84	0.0022	1,343
	meanALP TotSG	0.93	0.16	7,552	1,314	5.75	0.002			
2. N <sub>b</sub> -dugongs / block	Intercept			1,548	477	3.24	0.032	94	0.0016	834
	meanALP SG	0.36	0.11	7,484	2,223	3.37	0.028			
	meanALP possSG	0.79	0.11	591	80	7.36	0.002			
3. N <sub>b</sub> -dugongs / block	Intercept			-189	894	-0.21	0.841	86	0.00163	1,263
	N turtles	0.94	0.15	1.82	0.30	6.17	0.002			
4. N <sub>b</sub> -turtles / block	Intercept			1,373	512	2.68	0.044	66	0.0168	1,023
	meanALP TotSG	0.84	0.24	3,527	1,001	3.52	0.017			
5. N <sub>b</sub> -turtles / block	Intercept			1,597	425	3.756	0.013	72	0.0102	930
	meanALP possSG	0.87	0.218	336	84	4.007	0.010			

meanALP TotSG = mean area / block (km<sup>2</sup>) of large (> 1km<sup>2</sup>) total seagrass patches (likely + possible classes). Similarly, meanALP SG = mean area of large likely seagrass patches / block and meanALP possSG = mean area of large possible seagrass patches / block. N<sub>b</sub>-dugongs = block population estimates of dugongs (Model 6) and N<sub>b</sub> turtles = uncorrected block numbers. b\* = standardised regression coefficient used to compare variable importance in multiple partial regression models. Adj R<sup>2</sup> = adjusted R<sup>2</sup>. b\* = standardised regression coefficient and SE<sub>b</sub>\* its standard error. b = regression variable coefficients and SE<sub>b</sub> its standard error. t = t-test and P value for the constant and variables in the regression equation. P<sub>reg</sub> = significance of regression equation and its P value. N in all regression models is 7 (number of blocks).

### Integrating Indigenous and scientific knowledge of dugongs

The main aim of the WAMSI dugong project is to integrate Indigenous Ecological Knowledge of dugongs with scientific survey data (see Section 2 below) to help develop culturally appropriate and more effective monitoring and decision support tools for dugong management, and this requires new approaches. The use of Bayesian probability methods that recognise both the intrinsic value of expert knowledge and quantitative data is one approach being assessed, and has been used extensively to integrate knowledge from a variety of sources. For example, McGregor *et al.* (2010) integrated Indigenous Ecological Knowledge of traditional wetland burning practices on Kakadu National Park with scientific knowledge of vegetation-fire responses using a Bayesian Belief Network (BBN). BBNs that graphically and transparently highlight the contributions of all knowledge sources is a powerful tool that facilitates stakeholder engagement and communication for natural and cultural resource management (Bayliss *et al.* 2007). The Bayesian approach has proved versatile in almost every ecological field that involves making decisions in the face of risk and uncertainty, variability in scientific data, and social and biophysical complexities.

A major constraint to the identification of important dugong areas in the Kimberley for future monitoring and management purposes is the inherent uncertainties and measurement errors normally associated with the collection of observational data over very short time frames. Hence, a Bayesian approach was used to integrate “instantaneous” slices of scientific data with Indigenous Knowledge accumulated over millennial time-scales and encompassing all seasonal conditions. Bayesian probabilities of the likely occurrence of dugongs in the Kimberley were therefore derived for each 5 km grid cell from three available and different knowledge sources. These were there: (i) the Sept-Oct. 2015 aerial survey data (Fig. 6a; probabilities derived from re-scaled abundance data from zero to maximum value); (ii) the seagrass map (here only the “likely” seagrass class, Fig. 6; probabilities were derived from the % cover of seagrass / grid cell; and (iii) The intersection of cultural hunting areas with the data grid (Fig. 6c; hunting areas were allocated a probability of 1.0 and non-hunting areas 0).

The Bayesian probabilities are joint conditional probabilities ( $P_j$ ) of the interaction between the three for all possible combinations ( $P_c$  cultural;  $P_{sg}$  seagrass;  $P_d$  dugong abundance), as illustrated in the Venn diagram (Fig. 7) below and the formula.

$$P_j = P_d + P_{sg} + P_c - (P_d * P_{sg}) - (P_d * P_c) - (P_c * P_{sg}) + (P_d * P_{sg} * P_c)$$

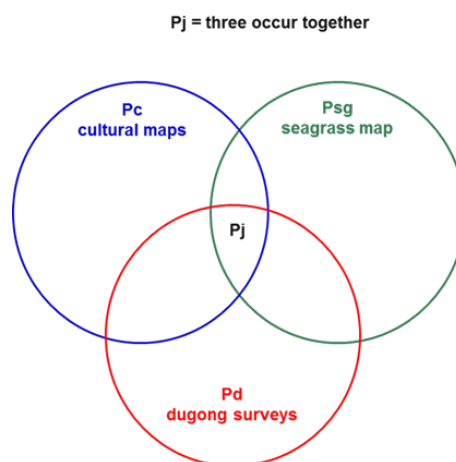


Figure 7. Venn diagram showing the joint intersection ( $P_j$ ) when all three sources of dugong knowledge occur together (note:  $P_j$  can occur in other combinations, just 1 or just 2 or all 3; see equation).

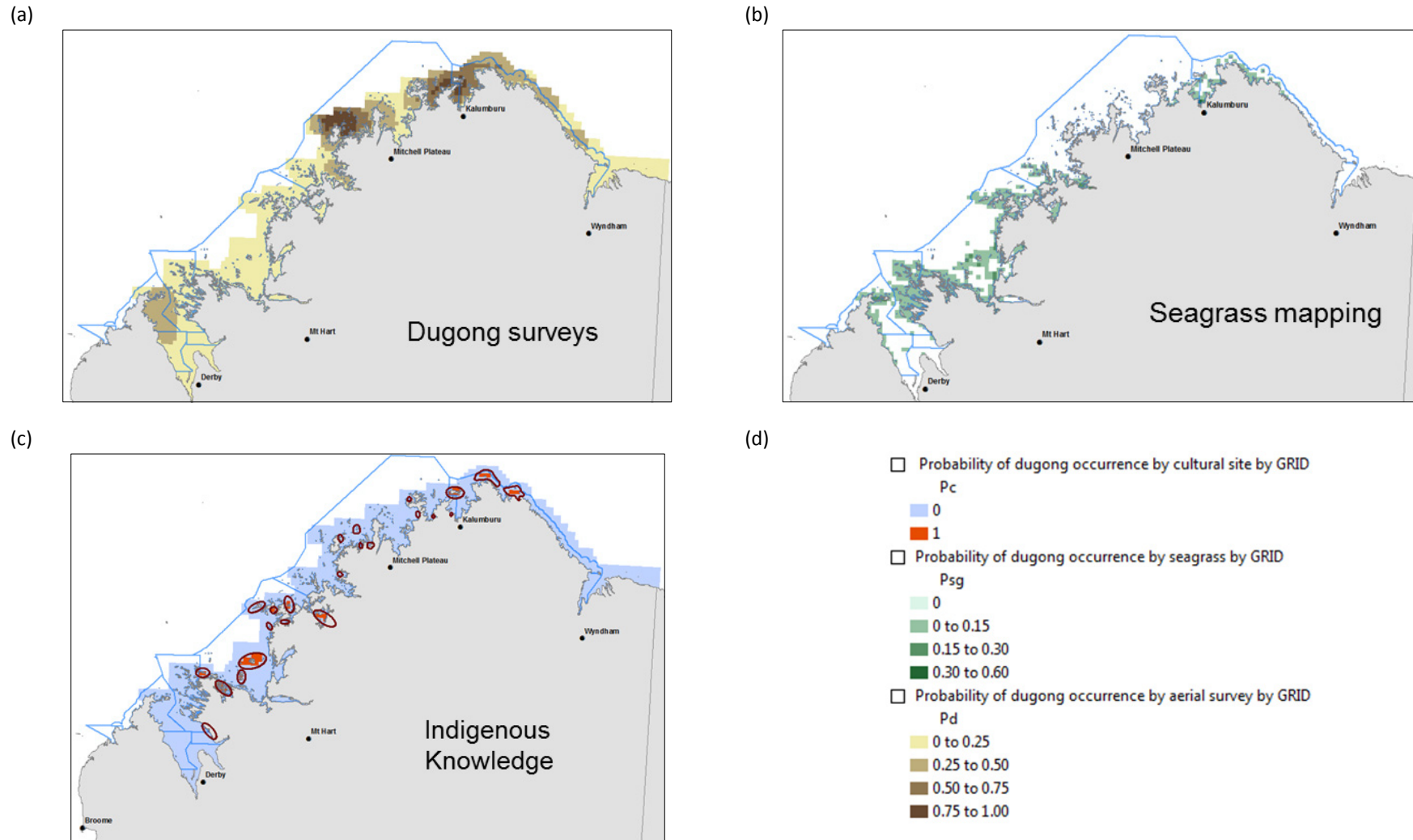


Figure 6 a-c. Integrating Indigenous and scientific knowledge using Bayesian probabilities. (a) Probability of dugong occurrence based on estimates of corrected numbers derived by aerial survey, (b) the probability of occurrence of seagrass based on the percentage cover of likely seagrass, and (c) the probability of occurrence (1.0 or zero) based on the location of known cultural hunting sites (from Healthy Country Plans). Joint probabilities (see text) are derived for each 5 km grid cell. Only the location of Native Title sea country boundaries are shown.

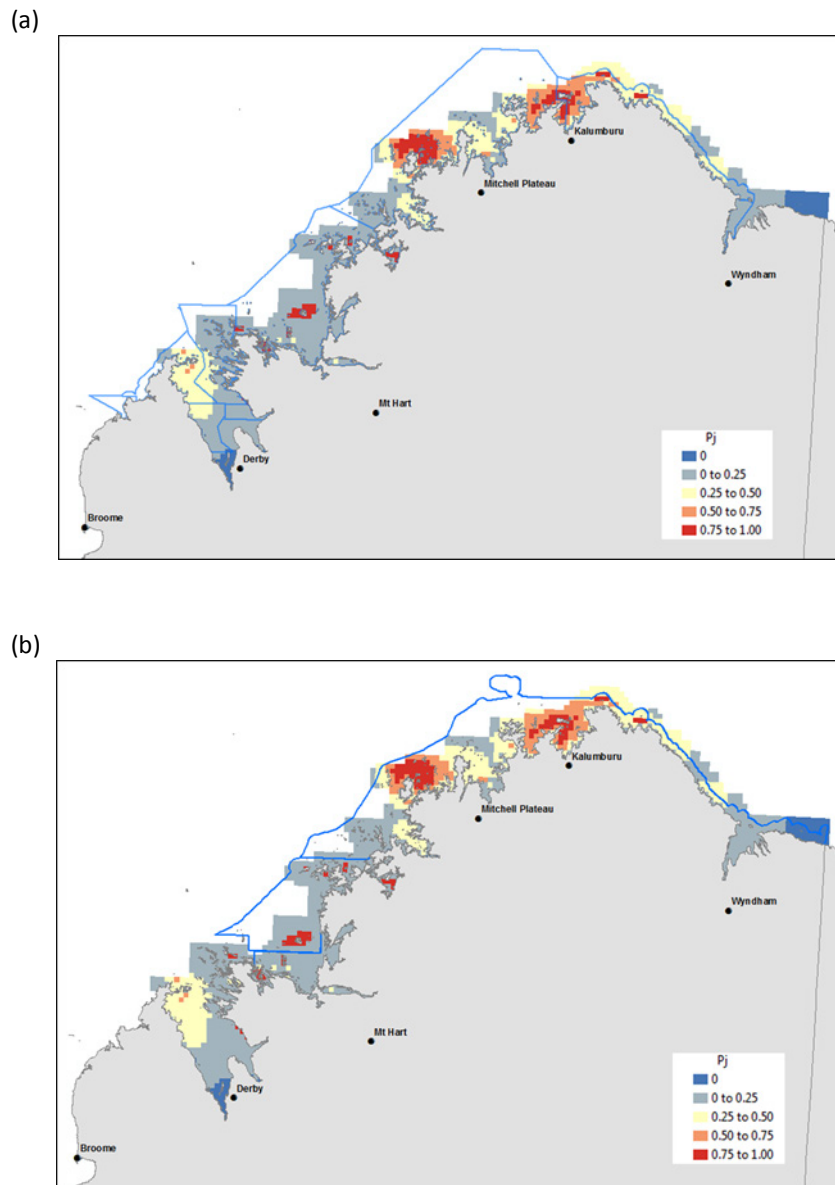


Figure 8 a-b. Likelihood of dugong occurrence. Map of Bayesian probabilities of dugong occurrence across the 5 km survey grid combining Indigenous Ecological Knowledge (hunting sites), the preliminary map of seagrass extent (Anstee 2014; using only the likely seagrass classification) and the Sept. – Oct. 2015 aerial survey data (see text) for (a) Native Title sea country and (b) proposed and existing marine reserve areas. Red colours denote high probabilities of occurrence and blue colours low.

Figure 7 maps the combined probabilities of dugong occurrence across the survey grid using all currently available knowledge sources, and highlights important areas. Whilst it is only a “first pass” probability map it can be continually updated with new information (called “*priors*”), such as: dugong cultural maps for Bardi Jawi, Myala and Nyul Nyul sea countries; increased calibration and validation of the preliminary seagrass map; and additional aerial surveys in smaller areas in other seasons to capture possible seasonal differences. The absence of extensive dugong abundance “hotspots” in Dambimangari country may be a seasonal artefact, given both the extent of mapped seagrass and the importance of Montgomery Reef and other nearby areas as dugong cultural sites.

### Other marine wildlife species

Similar sighting and abundance “hotspot” maps have been produced for snubfin dolphins (Appendix Fig. A5 a-d; sightings = 83), all “other” dolphins combined (Appendix Fig. A6 a-d; n=366) and large turtles (Appendix Fig. A7 a-d; n=1,311). Figure A8 illustrates sightings by all observers of bottlenose dolphins (n=20), spinner dolphins (n=13), false killer whales (n=6) and humpback whales (n=14). The high proportion of dolphins classed as “unknown” (327/449, ~73%) suggests that further training in dolphin species identification during aerial survey is required to increase the value of future survey data.

### *1.3 Discussion of aerial survey results*

The results reported here are preliminary in nature only as further population analyses and modelling are required prior to publication. For example, the potential bias from miss-identification of dugongs and snubfin dolphins where they co-occur in high numbers. These analyses are underway and will be reported in the final milestone report. Similarly, the pattern analyses between dugongs and seagrass are preliminary in nature only and require further spatial modelling that includes uncertainty in the spectral classifications.

A comparison of the Kimberley population estimates with other regional estimates is underway and requires agreement with other dugong survey teams on what availability correction factors to apply as the standard. In the interim, however, our best estimate using the most recent Hagihara *et al.* (2014) corrections for visibility bias is  $11,839 \pm 1,391$  (11.8% SE) dugongs, a density of  $0.36 \pm 0.04 \text{ km}^{-2}$  over ~33,165  $\text{km}^2$ . The Pollock *et al.* (2006) method yielded a similar estimate of abundance with a much lower standard error that is likely a statistical artefact ( $12,171 \pm 4.7\%$ ). In contrast, the recent NT dugong survey (R. Groom pers. comm.) yielded an estimate of  $8,176 \pm 958$  (11.7%), an average density of  $0.09 \text{ km}^{-2}$  over 93,145  $\text{km}^2$ . The four-fold difference likely reflects: (i) the Kimberley survey being restricted to shallow coastal waters < 20m bathymetry whilst the NT surveys included offshore deeper areas with zero to few dugongs; and (ii) the NT survey was in two parts, east and west of Cobourg Peninsula, with the western part having fewer dugongs compared to the east. The Bayliss and Freeland (1989) NT GoC survey offers a comparison when using the same population estimation methodology. For example, using the Marsh and Sinclair (1898a) correction for visibility bias they reported a density of  $0.60 \pm 0.11 \text{ km}^{-2}$  and, in contrast, the recent NT survey yielded a similar estimate ( $0.58 \text{ km}^{-2}$ ). Their Pollock *et al.* (2006) estimate in the east yielded a similar density to the Kimberley survey ( $0.35$  cf.  $0.30 \text{ km}^{-2}$ ). These comparisons highlight the importance of using a standardised approach to population estimation but, nevertheless, the initial figures indicate that the high density dugong-seagrass areas in the NT GoC region are comparable to results for Kimberley waters (or vice versa).

In general the highest densities of dugongs were found in survey blocks 5 and 6 ( $0.55 \pm 0.15 \text{ km}^{-2}$  &  $0.69 \pm 0.17 \text{ km}^{-2}$ , respectively), reflecting the greater abundance of seagrass (both likely & possible classes), which in turn reflects the greater area of shallow clear water < 20m bathymetry. Both these survey block are encompassed within the Wunambal Gaambera sea country and the proposed North Kimberley marine park. The lowest dugong density, ~ 9 times less than the high density blocks, was found in block 9 ( $0.07 \pm 0.02 \text{ km}^{-2}$ ), reflecting the least area of shallow coastal water < 20m bathymetry and the turbid waters of Joseph Bonapartes Gulf towards the NT border. The remainder of the blocks had similar dugong densities ranging between 0.22 and  $0.31 \text{ km}^{-2}$ .

The Bayesian approach to mapping probabilities of dugong occurrence that integrates all available knowledge sources, particularly Indigenous Ecological Knowledge, is likely the most useful approach to identifying key dugong areas given the inherent limitations associated with “one-off” scientific surveys. For example, the high cost of undertaking broad-scale baseline aerial surveys over large geographic areas means that they are generally only done at low sampling intensity (~6% in the Kimberley & elsewhere), in one season and, on average, about every 10 years thereafter if that. The

absence of extensive dugong abundance “hotspots” in Dambimangari country in the October 2015 survey may be a seasonal artefact given both the extent of mapped seagrass and the occurrence of hunting sites. However, a powerful advantage of the Bayesian approach is that it facilitates continuous updates with new information, or “priors”, which is simply adaptive monitoring and management (Holling 1978; Walters 1997). For example, future updates can include: incorporating dugong cultural maps for Bardi Jawi, Myala and Nyul Nyul sea countries; increasing the certainty level of the seagrass map with targeted and strategic calibration and validation field studies (and/or include the uncertainty level in the “possible” seagrass class); and undertaking additional aerial surveys in hotspot and cold spot areas in other seasons to capture seasonal differences; and so on.

## 2 Indigenous Ecological Knowledge

Aboriginal and Torres Strait Islanders are major stakeholders in the management and protection of Australia's natural and cultural coastal resources. Traditional Owners have cultural and legal rights, and responsibilities, to sustainably use and manage their extensive land and sea country. They have deep ongoing connections to both land and sea and recognise them as inseparable, requiring research approaches and management solutions that embrace Indigenous perspectives, values, knowledge and aspirations from the outset (Bayliss *et al.* 2014; National Marine Science Plan).

Saltwater people make extensive sea journeys in some places such as Torres Strait, whilst in other places use is restricted to coastal and intertidal areas (Smyth 2007, Barnett and Ceccarelli 2007). Dugongs (Nursey-Bray *et al.* 2010, Crase 2008, Marsh *et al.* 1999), sea turtles (Limpus and Chatto 2004) and many species of fish are important to Indigenous people and migrate between inshore areas along the coast and marine areas offshore, often long distances into Commonwealth waters, adjacent State/Territory waters, international waters or neighbouring countries. Indigenous people have sought recognition for their ongoing role in coastal ownership and management through numerous inquiries, forums, planning processes and legal claims. For example: the Coastal Zone Inquiry 1992-3 (Resource Assessment Commission 1993); the Turning the Tide Conference (1993); bioregional marine planning (National Oceans Office 2002, 2004); in the Kimberley sea country planning (e.g. North Kimberley Saltwater Country Plan 2010) and Healthy Country Planning (WGAC 2010, BAC 2011, DAC 2012, Bardi Jawi 2013); land and native title claims (AIATSIS 2012; the National Native Title Tribunal (2014); fisheries consultative committees (FRDC 2012); the National Oceans Office (2002), (2004); the National Sea Change Task Force (2014); other national workshops (NAILSMA 2012); and regional government planning processes (DEC 2009; DPaW 2013). Indigenous people have cultural, linguistic and environmental knowledge about the marine-coastal domain in the Kimberley, which is intimately tied to local ownership and traditional management protocols. Indigenous knowledge encompasses the interconnectedness of people with the natural world, and the maintenance, transmission and continued development of such knowledge are important objectives for all Indigenous groups. Hence, Indigenous communities are themselves research and knowledge generators. A priority for Indigenous coastal knowledge today is the emphasis on co-generated research that will improve the social and economic wellbeing of communities by facilitating sustainable natural and cultural resource management of traditional land and sea country, and this approach is adopted by the WAMSI dugong project through partnership and full participation of Balangarra, Wunambal Gaambera, Dambimangari and Bardi Jawi ranger groups.

The partnership approach appears to have been successful with respect to the scientific components of the dugong project (mapping distribution & abundance via aerial survey; the impending movement study using tagging technology) and now requires a two-way exchange with the WAMSI 1.5 IEK project. We look forward to interacting with project 1.5 by invitation and as it builds up momentum to completion in June 2017. One constraint, however, is that whilst we have a very specific focus on dugongs the IEK project has a very wide mandate on, and responsibility for, all culturally significant marine species. To this end we trialled a selective 2-day interview process with

Dambimangari elders and senior TOs who have local and cultural knowledge of dugongs. The focussed interviews were successful providing important insights into the cultural value of dugongs and additional information on dugong sites (see Attachment 1, interview report by E. Woodward). We plan to extend this process to other Kimberley groups who willing to share dugong stories, and we are hoping interview elders and senior TOs on both dugongs and turtles with Balanggarra in September. We will continue to interact with project 1.5 by invitation and as it builds up momentum. Links will continue to be made with the WAMSI turtle project via Scott Whiting and Tony Tucker (DPaW), and now that we have data to share we will also develop links with the WAMSI dolphin and the MSE projects (Fabio & Hector).

Field work for the movement component of the dugong project was shifted from April to August this year to accommodate the time needed to obtain CSIRO Animal Ethics Committee (AEC) using a new capture technique called the Dermal Holdfast (DHF) method (developed in Torres Strait by the James Cook University dugong research team), obtaining additional acoustic receivers and the tailstock harnesses/tethers to attach the satellite tags, and arranging logistics with Bardi Jawi and Dambimangari rangers. The AE application has been approved and an application to DPaW for a scientific licence has been submitted. All equipment is on hand and capture-boat teams and a field agenda is being finalised. The location of the capture-study area now encompasses waters from One Arm Point through to Koolan Island and down to Talbot and Dugong Bays in Dambimangari country and the proposed Horizontal Marine Park. The study area will be extended to Pender and Beagle Bays in the event that we cannot reach our catch quota and need to move west. A comprehensive description of the study design, capture and tagging methods, the field trip plan and team composition is found in the AEC application and attached to this report (Attachment 2).

## **Communication and knowledge transfer**

### **Personnel and staffing:**

Peter Bayliss is the Project Leader with support from other CSIRO science leaders and WAMSI Project Leaders (Stuart Field, Kelly Waples). TJ Lawson (CSIRO Melbourne) is the project's data manager and GIS specialist. Emma Woodward (CSIRO Perth) has carriage for Indigenous community participation and engagement, and leads the Indigenous Knowledge component of the project. However, she is currently on maternity leave until January 2017 and due to the difficulty in finding a replacement within CSIRO Peter Bayliss will take her place until then. Richard Pillans (CSIRO Brisbane) has extensive experience with satellite and acoustic tagging of marine megafauna and will participate in field work for the movement study in August 2016. The project is continually supported by CSIRO support staff (Greg Lyden & Wendy Steele) with oversight by Andy Steven, Research Director of the Coastal Development and Management Program.

### **Data/metadata reporting:**

Data from completed Phase 1 of the project have been made available to WAMSI via the CSIRO MarLIN and Bowen DAP using our metadata protocols. Data and metadata updates were provided for the November 2015 milestone report, and GIS data and metadata for the June 2016 annual milestone report have been provided to participating Indigenous ranger groups and DPaW.

Aerial surveys for marine fauna in the Broome-Dampier Peninsula area of south Kimberley (Cape Bossut to Cape Leveque) were undertaken by Woodside in three consecutive seasons in 2009 (RPS 2010; SKM 2009). WAMSI has arranged access to the full data set to use as baseline for Kimberley dugongs and is a very valuable contribution for future regional analysis. All Woodside data were provide in GIS format on 29th February 2016.

### **Links to other projects:**

Relevant KMRP projects include: Remote Sensing (1.4); Indigenous Knowledge project (1.5); and Marine Turtles (1.2.2). A “first-pass” benthic habitat/seagrass map was produced in Phase 1 (Janet Anstee/CSIRO), which now has strong links to other WAMSI seagrass researchers across different projects (e.g. Gary Kendrick, Renae Hovey & Leonardo Ruiz Montoya UWA; Mat Vanderkluft & Janet Anstee CSIRO) and DPaW (Andy Halford). An informal working group has been established to share data/ideas in order to further calibrate Janet’s seagrass map. Janet will also link with Jim Greenwood’s project 1.4 (potential of benthic irradiance to predict seagrass distribution). The original plan was to use information from project 1.5 to inform the aerial survey and tagging designs in Phase 2, and to integrate IEK with subsequent scientific data on distribution and movement patterns. Whilst the IEK project has recently gained momentum much of the dugong IK work was done through participating Indigenous partners in the aerial survey component, the provision of access to cultural maps in their Healthy Country Plans, and through several HC Planning workshops undertaken jointly by CSIRO and the KLC for other projects. To increase the chances of obtaining sufficient information to undertake the integration of Indigenous Knowledge of dugongs with scientific survey data we have trialled a focussed informal interview process with Dambimangari elders and senior TOs who have local and cultural knowledge of dugongs (see above). The focused interviews were successful in providing new and important insights into the cultural value of dugongs, and we hope to extend this process to other groups willing to share dugong stories. We will develop links to the 1.5 by invitation as it progresses. Links will continue to be made with the WAMSI turtle project via Scott Whiting and Tony Tucker (DPaW) when needed. Links will be made with the Management Strategy Evaluation (MSE) project lead by Fabio Boschetti and & Hector Lozano-Montes (CSIRO).

### **Other issues (including IP) and new or emerging risks:**

There is one current risk to the dugong project and one emerging risk. These are:

- (i) Delays to the start of the 1.5 Indigenous Knowledge project were necessary to have the right process in place but may also lead to delays in integrating Indigenous values into the dugong project. However, project 1.5 is quickly gaining traction and it is apparent that good progress could be made within the next 12 months, with flow on to the dugong project. Emma Woodward, who manages the IK component of the dugong project, has taken maternity leave and will return to work in January 2017. A temporary replacement within CSIRO could not be found so the project leader (Bayliss) has taken on this role.
- (ii) The movement study was re-designed (see section 3 above) due to changing circumstances, however is on track to commence in August with Bardi Jawi and Dambimangari rangers. If sufficient dugongs are tagged then about a year of movement and diving behaviour data will be obtained (see section 4 above). Besides catching insufficient numbers within two weeks, the main risk is not obtaining a good return on our capital investment past the end of WAMSI in June 2017. A long-term movement study of dugongs is a much sounder strategic goal and investment, and is highly recommended, particularly with respect to the acoustic array that can accommodate a number of species (e.g. sharks, whales, dolphins, turtles & fish). Data collection from acoustic tags should be extended past the end of WAMSI given that the battery life of transmitters is ~10 years. The cost of maintaining the acoustic receivers (i.e. change batteries every 15 months & download data) once animals have been tagged is minimal, and Indigenous ranger groups are ideally situated to do this.

**Communication Activities – Publications, Presentations, Media releases:**

Table 5. Summary of Communication Activities – Publications, Presentations and Media releases.

Communication Activity	Total to date
<b>Peer reviewed publication</b>	0
<b>Popular publication (i.e. Landscape, newsletter, etc – see comms section below)</b>  WAMSI Bulletin (newsletter) CSIRO Monday Mail (newsletter)	3
<b>Conference Presentation</b>  Bayliss P, Wilcox C and Vanderklift M (2015) Integrating Indigenous knowledge and survey techniques to develop a baseline for dugong ( <i>Dugong dugon</i> ) management in the Kimberley. WAMSI Conference 2015, April 2015, State Library of Western Australia, Perth.	1
<b>Presentations/Meetings with DPAW managers</b>	1 (phone meeting)
<b>Presentations/Meetings with Traditional Owners</b> – encompasses four main coastal-sea country Native Title/ranger groups – Balangarra, Wunambal Gaambera, Dambimangari & Bardi Jawi. Representatives from each group (e.g. ranger coordinators or Healthy Country managers) were part of a project steering committee that held regular meetings/email exchanges. TO groups are research partners in the dugong project.	4 workshops early 2015, 8 phone meetings, 1 3-day training course in aerial survey for 12 Indigenous rangers at Truscott was held in late August 2015.
<b>Presentations/Meetings with other stakeholders (i.e. industry, tourism)</b>	0
<b>Presentations to general public</b>	0
<b>Media releases</b>  In train - Kimberley Land Council newsletter/media release; Science Network WA; & interviews/story for ABC will be arranged	1 (via WGAC - ABC), 1 Science Network WA, ABC is train & will focus on the movement study
<b>Radio interviews (here ABC radio story)</b>	1
<b>Newspaper articles (Kimberley Echo – see comms section below)</b>	1
<b>Other</b> (internal progress report: Phase 1 milestone report; Phase 2 short report on aerial survey dugongs); annual milestone report 2/2	3

The following links demonstrate our project communication activities outlined in Table 4 (as reported in our previous 2/1 milestone report).

- WAMSI Bulletin:  
<http://www.WAMSI.org.au/news/WAMSIcsiro-partner-kimberley-aboriginal-groups-manage-dugong>
- CSIRO Newsletter – Monday Mail:

<http://my.csiro.au/News-and-events/News-Listing-Page/2015/November/9/CSIRO-partners-with-Kimberley-Aboriginal-groups-to-manage-dugong.aspx>

- The Kimberley Echo (Kununurra WA local news) ran the following story after interviewing the survey team: <https://au.news.yahoo.com/thewest/wa/a/29872077/researchers-rangers-count-dugongs-in-aerial-survey/>

WGAC with CSIRO assistance issued a Media Release (2<sup>nd</sup> October 2015) on the aerial survey training course run at Truscott, which was later picked up by ABC Radio.

1. **Management Questions** What are the distribution and abundance of dugongs in the selected areas of Kimberley coastal waters and, depending on the availability of additional resourcing, what are their movement patterns in a marine park (or proposed marine park) (to be determined with DPAW & Traditional Owners)? (PRI)
  2. What, when and where are their critical habitats in the selected areas of the Kimberley? (PRI)
  3. What are the appropriate spatial management units for this priority species given the data that are available? (SEC)
  4. What environmental factors may influence the above (1) distribution and abundance patterns and population characteristics (e.g. seagrass extent, bathymetry etc)? (SYN)
  5. What are the major pressures on dugongs in this region and how can they be measured using key indicators over the long-term (e.g. marine debris) (SEC)
  6. What cost-effective methods can be developed to enable effective condition and pressure monitoring of dugong? (PRI)
- **Key Stakeholders/End-users** Balanggarra, Wunambal Gaambera, Dambimangari, Bardi Jawi and the Kimberley Land Council are the main indigenous stakeholders, but the project may also engage Myala, Nyul Nyul and Yawuru Traditional Owners with an additional aerial survey training course and during the movement study in August 2015.
  - DPaW.

#### **Outputs** (What do they want?) – For the aerial survey component

List the outputs expected from the research, including the format in which these will be presented.

#### *Phase 2/2*

- The outputs will attempt to address the management questions listed above and will include spatial information on the distribution and abundance of dugong and other marine species, scientific publications and operating procedures for joint managers with respect to the design of a cost-effective monitoring program for dugongs using aerial and boat survey methodology (see Jackson *et al.* 2015 for turtles & seagrass monitoring). The final scope of these outputs will be provided once comprehensive analysis of aerial survey data has been completed for the 2<sup>nd</sup> Phase 2 milestone report by June 2016.

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dugong aerial survey data.

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## Appendices

Appendix 1. Practice surveys.

Appendix 2. Survey design variables.

Appendix 3. Perception bias for dugong groups and individuals.

Appendix 4. Availability bias for dugong groups and individuals.

Appendix 5. Estimates of abundance using different models (to compare historical data in other regions).

Appendix 6. Ancillary survey data – sighting maps of snubfin, other dolphins and humpback whales.

## Attachments

1. Dambimangari interviews undertaken 23-25<sup>th</sup> November 2015 in Derby for WAMSI Dugong project (prepared by Emma Woodward). Held IN CONFIDENCE until the Dambimangari Board of Directors approve distribution.
2. Dugong movement study using satellite and acoustic tags. Approved Animal Ethics Application.

### **Certification**

I certify that the reporting is complete and accurate to the best of my knowledge, and I have reported any substantial deviation from the Project Plan and matters which I believe may affect the ability of the project to meet its objectives. I certify that each Project Party has provided Contributions as required under the Project Agreement.

Project Leader:

Peter Bayliss



Date:

8<sup>th</sup> June 2016

***This section needs to be signed for the Final Project Report only by the relevant Joint Venture Partner Executive.***

### **Certification**

I certify that this report has been reviewed by the agency and reflects the standards of this agency in reporting.

WAMSI JV Partner

Executive:



CSIRO Tim Malthus (acting Research Director)

Date:

June 2016

***The section below is completed by WAMSI***

Metadata up to date – confirmed by Data Manager:

Date:

Milestone Report approved by Node Leader:

Date:

Milestone Report approved by WAMSI:

Date:

## Appendix 1. Practice surveys

Four 2-hr practice sessions were undertaken with Unguu and Balangarra rangers (21-24 Sept.) on the survey team prior to commencement of surveys due to logistical delays that allowed observers to obtain fresh search images of dugongs and other species, and to practice use of the complex data recording system and team coordination. A comparison of experienced vs. inexperienced observer counts in tandem pairs, and between port and starboard front observers, is shown in Figure A1 and A2 respectively. Results show the expected pattern between experienced and inexperienced (i.e. < 30 survey hrs) observers and highlights the importance of standardising observer differences with aircraft position-observer-specific correction factors for perception bias (i.e. those animals/groups available to be detected but missed). The important learning from the practice sessions was the need for observers to aim for consistent and stable counts rather than maximising counts after long survey times. Data were not used in population assessments although contributed to distribution maps.

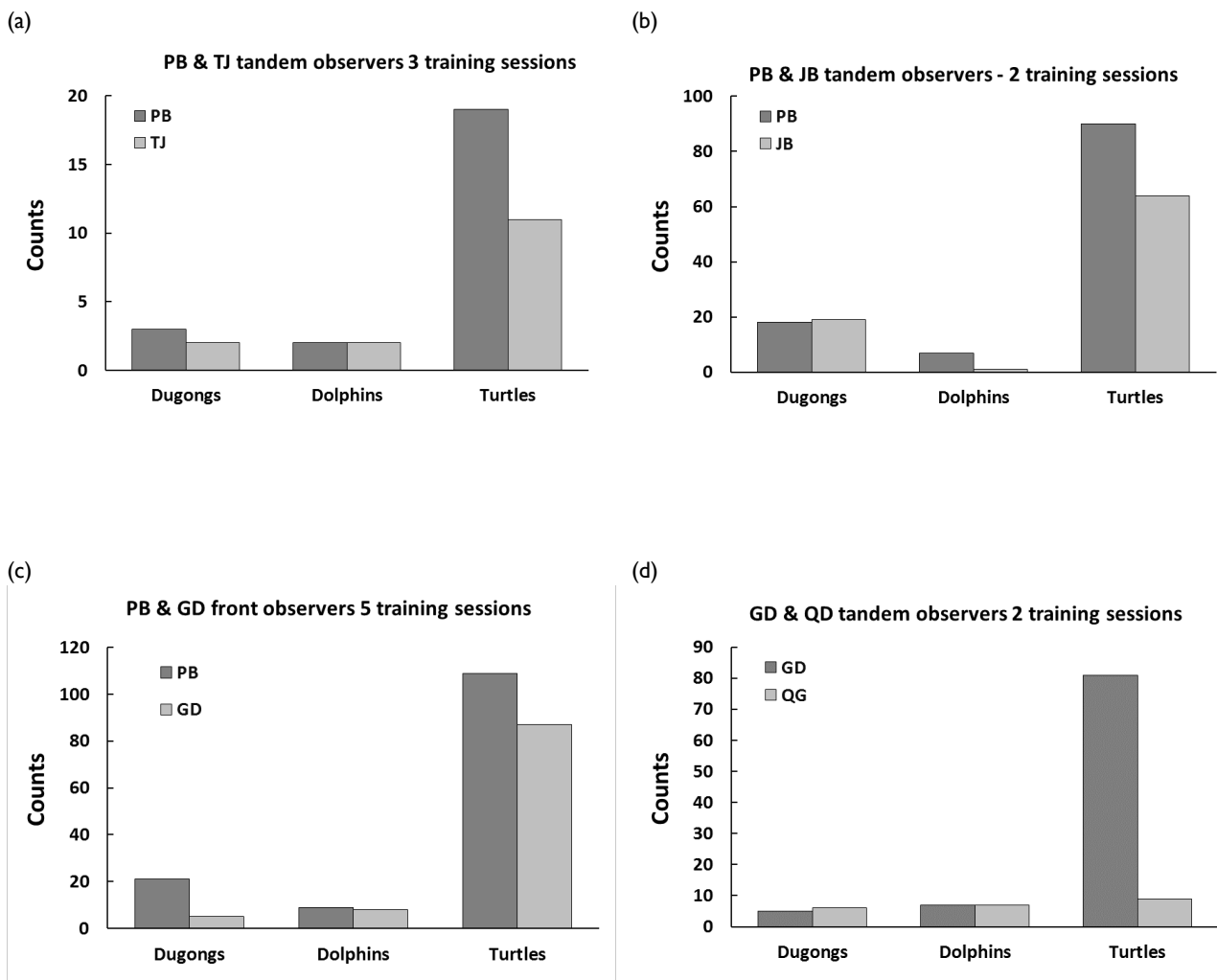


Figure A1a-d. Comparison of experienced vs. inexperienced observer counts in tandem pairs, and between port and starboard front observers, during pre-survey practice sessions at Truscott (21-24 Sept. 2015). Observers: PB (Peter bayliss); TJ (TJ Lawson); GD (Glenn Dunshea); QG (Quentin Gore); JB (James Birch). Not all data graphed due to changes in aircraft positions by some trainees.

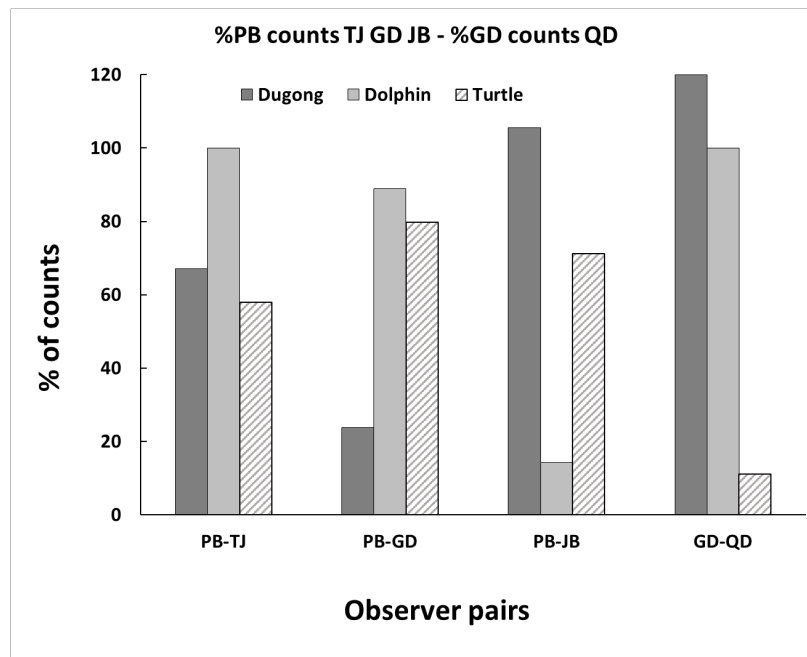


Figure A2. Comparison of experienced vs. inexperienced observer counts in tandem pairs as a percentage of experienced observer counts during the pre-survey practice sessions at Truscott (21-24 Sept. 2015). The comparison between experienced port and starboard front observers is based on the % of PB counts. See above for observer codes.

## Appendix 2. Survey design

Lengths of transects (km) over water (Fig. 1a) were measured in a GIS (ArcMap™ 10.2) and distances adjusted according to the actual flight path using track log data from a Garmin GPS. Distances over land (islands) were deducted from the total length. Areas (km<sup>2</sup>) for over water sample transects were then derived for a 0.4 km wide transect by combining the 200-m transect widths of port and starboard front observers (Table A1). The area of each logistically defined survey block was calculated between the 20m bathymetry line and the coastline in GIS, and used to estimate percentage (%) sampling intensity (%SI) per block (Table A1).

Table A1. Summary of the sample area (km<sup>2</sup>) and sampling intensity (%SI) per survey block (Fig. 1b blocks 3-9). Overall mean sampling rate was ~ 6%.

Survey block	Block area km <sup>2</sup>	Transect area km <sup>2</sup>	% SI
3	8,055	477	5.9
4	7,669	534	7.0
5	5,318	343	6.5
6	5,339	320	6.0
7	2,031	116	5.7
8	2,105	68	3.2
9	2,648	99	3.7
<b>Total</b>	<b>33,165</b>	<b>1,957</b>	<b>5.9</b>

### Appendix 3. Perception bias for dugong groups and individuals

Table A2 summarises the port and starboard tandem observer combinations in the aircraft used to derive double counts (see Bayliss 1986) to correct for perception bias (Cp; dugong groups/individuals that were available to be detected but missed by observers). The counts of groups and individual dugongs of front port and starboard observers across all transects for each survey block used in population estimation are summarised in Table A3.

Table A2. Summary of tandem observer combinations (Sept. – Oct. 2015) used to derive double counts (see Bayliss 1986) to correct for perception bias (Cp; dugong groups/individuals that were available to be detected but missed by observers).

Date	Type	Port		Starboard	
		Front	Rear	Front	Rear
21/09	Training	PB	TJ	GD	MC
23/09	Training	PB	JB	GD	QG
24/09	Training	PB	JB	GD	QG
25/09	Survey	PB	TJ	GD	-
26/09	Survey	PB	TJ	GD	MC
27/09	Survey	PB	TJ	GD	MC
28/09	Survey	PB	TJ	GD	-
1/10	Survey	PB	EJ	TJ	EK
2/10	Survey	PB	EJ	TJ	EK
3/10	Survey	PB	JH	TJ	EK
4/10	Survey	PB	-	TJ	JH
5/10	Survey	PB	-	TJ	AH
6/10	Survey	PB	-	TJ	-
7/10	Survey	PB	QG	TJ	JB
8/10	Survey	PB	-	TJ	JB

Observers: PB (Peter Bayliss) and TJ (TJ Lawson) CSIRO; GD (Glenn Dunshea EMS consultant); mc (Maggie Captain) Wunambal Gaambera; QG (Quentin Gore) and JB (Birdie James Birch) Balanggarra; EJ (Ethan Jungine), EK (Erwin Kibily) and Jarrad Holmes (JH) Dambimangari; AH (Azton Harwood) Bardi Jawi.

Table A3. Summary on-survey counts of groups and individual dugongs (Sept.-Oct. 2015) by front port and starboard aircraft positions for each survey block.

Block	Groups			Individuals		
	Port	Starboard	Total	Port	Starboard	Total
3	12	2	14	30	2	32
4	2	7	9	16	13	29
5	18	17	35	44	21	65
6	28	28	56	56	14	70
7	6	2	8	12	4	16
8	2	2	4	3	2	5
9	1	1	2	1	1	2
Total	69	59	128	162	57	219

Table A4 a-c. (a) Summary of selected observed group statistics used in population analysis. (b) Perception bias (detection probability  $P \pm SE$ ) for groups and associated correction factor ( $CF \pm SE$ ) and similarly for (c) individuals.

(a) Groups

Observer	Plane position	Count	N groups	Range	MGS	CVg <sup>1</sup>
PB	Port Front (21/9 to 8/10)	76	38	1 - 6	2.00	0.10
GD	Starboard Front (21/9 to 28/9)	29	49	1 - 6	1.69	0.15
TJ	Starboard Front (1/9 to 8/9)	17	8	1 - 5	2.13	0.26

(b) Perception bias groups

Observer	Plane position	P	SE (P)	CF	SE (CF)
PB	Port Front	0.68	0.06	1.47	0.09
GD	Starboard Front	0.63	0.14	1.59	0.22
TJ <sup>2</sup>	Starboard Front	0.51	0.05	1.96	0.09

(c) Perception bias individual counts

Observer	Plane position	P	SE (P)	CF	SE (CF)
PB	Port Front	0.78	0.04	1.28	0.05
GD	Starboard Front	0.79	0.06	1.27	0.07
TJ	Starboard Front	0.51	0.05	1.95	0.10

Note

1. See Marsh & Sinclair (1989a) for calculation of Coefficient of variation (CV) for mean groups size (MGS).
2. Insufficient double counts to develop a group CF on the starboard side for TJ due to missing tandem observers on some occasions. TJ saw 75% of PB counts (12 cf. 16 groups from 1/10 to 8/10) and an observer CF was of 1.33 was applied with the PB CFp of 1.47 (overall CpTJ = 1.96 & PBs 5% SE of 0.09 used).

*Dugongs and snubfin dolphins*

Dugongs and the Australia snubfin dolphin (*Orcaella heinsohni*) at first glance appear similar, the only striking difference being the small dorsal fin low on the dolphin's back and its propensity to occur in

larger, tighter groups compared to dugongs. Bayliss and Freeland (1989) reported that after several observations most observers had little difficulty differentiating between the two species under favourable viewing conditions. Additionally, they reported that < 1% observations had both species occurring together and, overall, only ~ 5% of total observations of dugongs and dolphins could not be classified. In contrast, however, more difficulty was experienced during the Kimberley survey and elsewhere (R. Groom pers. comm. for the NT). The only significant change to a rigidly standardised survey procedure, besides using a different suite of observers, is that survey height was increased from 137m (450 ft) to 152m (500 ft), suggesting a possible threshold for confident identification, and this was my impression. Observer experience is likely not a confounding factor as Bayliss and Dunshea, the only two who recorded snubfins on the Kimberley survey, both have > 300 hrs of marine survey experience. The NT survey team report also (C. palmer & R. Groom pers. comm.) that snubfin observations (& presence) significantly increased when using helicopters as observing platforms being able to fly much lower and slower compared to a fixed-wing aircraft flying faster and at higher altitude. Hence, further analysis and modelling work is required to ascertain the potential influence of miss-identification errors between dugongs and snubfins where they both co-occur at high density, particularly with respect to observations in the outer edge of transects (150-200m). An initial filtering of outer transect edge data yielded no huge difference in estimated dugong numbers or distribution maps of either species. However, future Bayesian modelling of dugong occurrence will include a 50% uncertainty level for potential miss-identifications at the outer edge of transects, but only where they co-occur along the same transects.

#### **Appendix 4. Availability bias for dugong groups and individuals**

Estimates of availability bias ( $P_a$ ) of observed dugongs and associated correction factor ( $C_a$ ) to adjust counts to estimates of absolute numbers have evolved over time and fall into three classes.

##### *i. The Marsh and Sinclair (1989a) $C_a$*

The probability of dugongs being available to be detected ( $P_a$ ) is calculated as  $0.167 / P_s$ , where  $P_s$  is the proportion of dugongs observed at the surface during a survey and 0.167 being the proportion estimated directly (i.e. in very clear water where detection of underwater dugongs is possible & from aerial photos; see Marsh & Sinclair 1989a and Bayliss & Freeland 1989 for details). For example, overall 80% of dugongs were seen at the surface during the Kimberley survey (Table A5) and this model assumes that  $P_a = 0.167/0.8$  were available to be detected ( $P_a = 0.21$ ; 79% unavailable), producing a  $C_a$  of 4.79 to be applied to counts corrected for perception bias ( $C_p$ ; those available but missed by observers).

Table A5. Summary of the number and percentage (%) of dugongs observed at the surface and under the water (including those diving) during the survey, used to calculate a CF (Ca) for the Marsh and Sinclair (1989a) method.

Block	Below surface	Surface	Block total	% Surface
3	1	30	31	97
4	3	12	15	80
5	16	49	65	75
6	12	54	66	82
7	1	15	16	94
8	6	4	10	40
9	1	1	2	50
Total	40	165	205	80

ii. *The Pollock et al. (2006) Ca*

This method addresses the fact that the Marsh and Sinclair (1989a) availability bias is not constant because survey condition with respect to water turbidity and sea state is a variable, despite the fact that considerable effort is made to only conduct surveys under a narrow range of acceptable environmental conditions. Pollock *et al.* (2006) directly addressed the influence of turbidity and sea state condition on availability visibility bias, although in their experimental approach they could only examine turbidity for two detection depths (0-1.5m & 0-2.5m) and two classes of sea state (Optimal  $\leq 3$  Beaufort scale & Marginal  $> 3$ ). Other environmental variables such as cloud cover (lighting), glare and tide were not considered high priority based on previous studies (e.g. Bayliss 1986; Marsh & Sinclair 1989a). Although their importance was recognised they assumed also that dugong detection availabilities during a typical aerial survey would not vary significantly between habitats (e.g. deep water offshore habitats c.f. shallow water inshore seagrass habitats), water depth (bathymetry) and related diving behaviour of dugongs. Hence, the proportion of dugongs available for detection is necessarily assumed constant for each of their experimental levels of survey condition with respect to sea state and turbidity. Nevertheless, data were available to develop extrapolation equations to address continuous variable conditions but not used, and this approach is adopted here (Fig. A3 a-d). Table A6 summarises turbidity conditions by survey block and associated availability correction factors ( $Ca \pm SE$ ) for Optimal and Marginal survey conditions using the prediction equations derived from data in Pollock *et al.* (2006).

Pollock *et al.* (2006) developed also a new Monte Carlo simulation method to address high sample errors typically associated with dugong transect data reflecting extremely patchy/clustered spatial distribution of animals over large areas and the fact that sample units are variable in size (i.e. sample data comprises mostly zeros with a small number of high counts). They applied a Variance Inflation Factor (VIF) to estimates of the sample variance to address clumping counts above an expected random distribution. However, the VIF method is re-examined here because the sample variance calculated by the Ratio Method for aerial survey data from unequal length transects (see Caughley & Grigg 1981) should address collinearity between variation in sample size and counts. Additionally, O'Brien (2007) recommended a cautionary approach to adopting the VIF method to reduce sample variation as results may be spurious for values  $> 8$  (& likely a characteristic of most aerial survey data).

Table A6. Summary of mean turbidity conditions by survey block recorded by the environmental (ENV) data observer (with values substituted from observer records when missing) and associated correction factors ( $Ca \pm SE$ ) for Optimal and Marginal survey conditions using the prediction equations in Figure A3a-d (data from Pollock *et al.* 2006).

Block	Turbidity ENV	Optimal		Marginal	
		Ca	SE (Ca)	Ca	SE (Ca)
3	4	2.137	0.25	2.729	0.313
4	2.9	2.122	0.244	2.122	0.238
5	3.2	2.264	0.277	2.264	0.278
6	3	2.183	0.259	2.183	0.256
7	3	2.172	0.257	2.172	0.253
8	4	2.729	0.319	2.729	0.313
9	4	2.729	0.319	2.729	0.313

Note: Sea State  $\leq 3$  on the Beaufort scale is Optimal and  $> 3$  marginal.

#### New Monte Carlo method to estimate sample variance

A new statistical method to reduce sample variation was developed and compared to the VIF method used by Pollock *et al.* (2006). The method involves fitting a probability density function (pdf) to describe the distribution of count data for each block to avoid the underlying normality assumptions of all sample statistics. BestFit™ software (Palisade 2015) was used to fit a range of distributions and selection of a pdf was based on the AIC statistic. The best asymmetric pdf for all survey blocks was a negative Exponential Function and its mean and Standard Deviation was used in lieu of the VIF in Monte Carlo simulations to account for non-normal distribution of transect count data due to extremely clumped dispersion of counts.

#### *iii. The Hagihara et al. (2014) Ca*

This method addresses the gap in the Pollock *et al.* (2006) approach by directly examining dugong detection probabilities for two viewing depths (0-1.5m & 0-2.5m) between habitats (e.g. deep water offshore habitats c.f. shallow water inshore seagrass habitats), water depth (bathymetry), tides and associated diving behaviour of dugongs obtained from a large sample of animals tagged with telemetry time depth recorders. They found that the proportion of dugongs available for detection varied most significantly with water depth then habitat with tidal condition having a minor influence. Data from Figure 2 in Hagihara *et al.* (2014) were reconstructed and re-analysed for application to the Kimberley survey (Fig. A4 a-d; Tables A7 & A8).

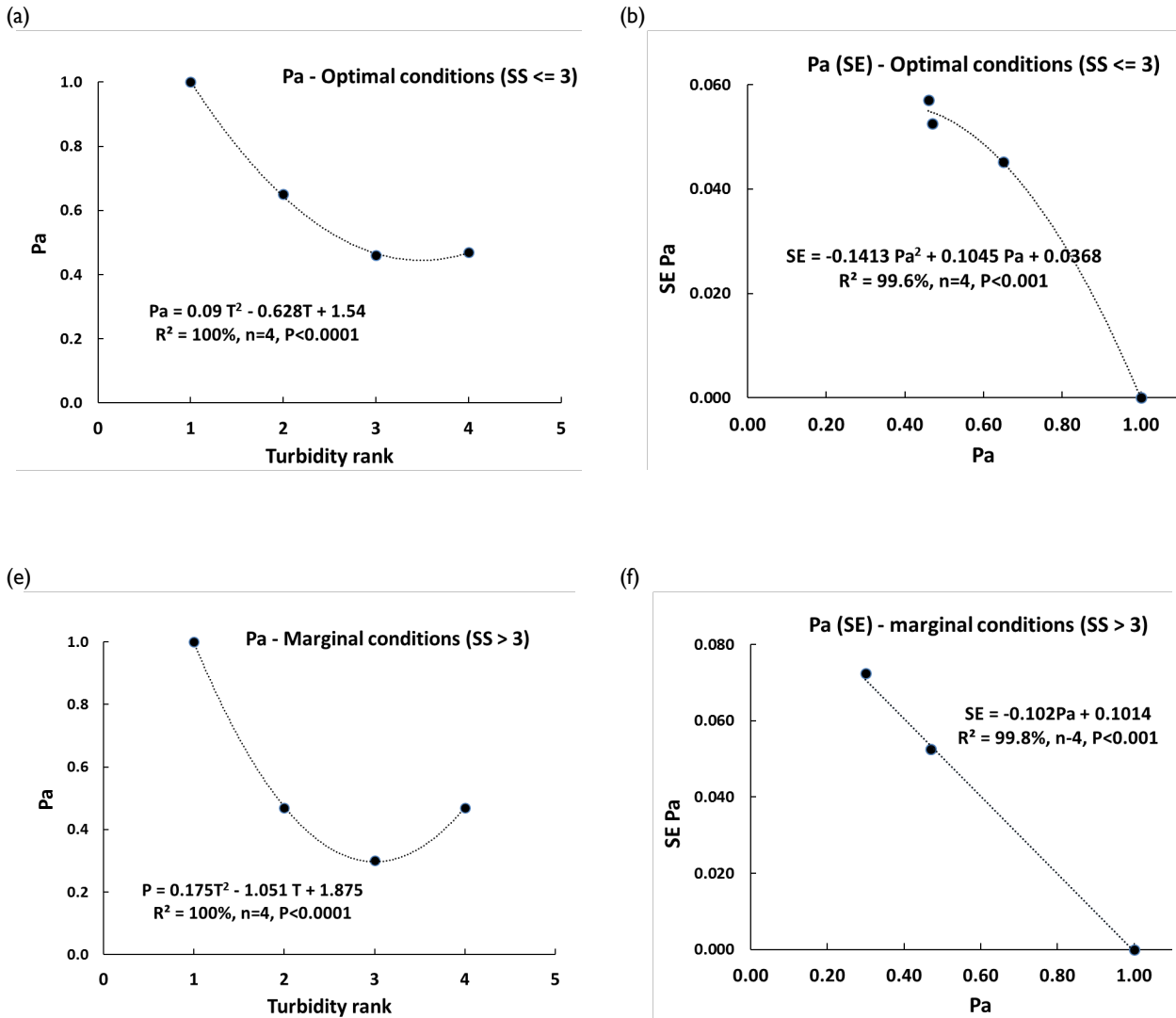
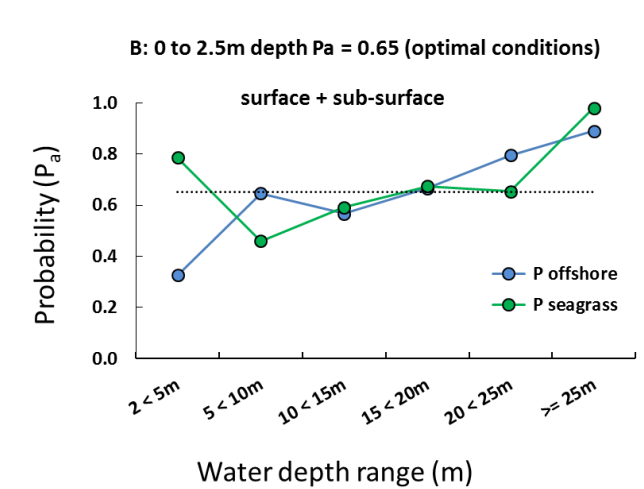


Figure A3 a-d. (a) Regression equations predicting availability probabilities (Pa) and (b) associated Standard Errors (SE Pa) of dugongs from turbidity rank (note maximum value is 4) for Optimal survey conditions (i.e. Sea State ≤ 3) and, similarly (c & d), for Marginal survey conditions (Sea State > 3). Data from Table 1 in Pollock *et al.* (2006).

(a)



(b)

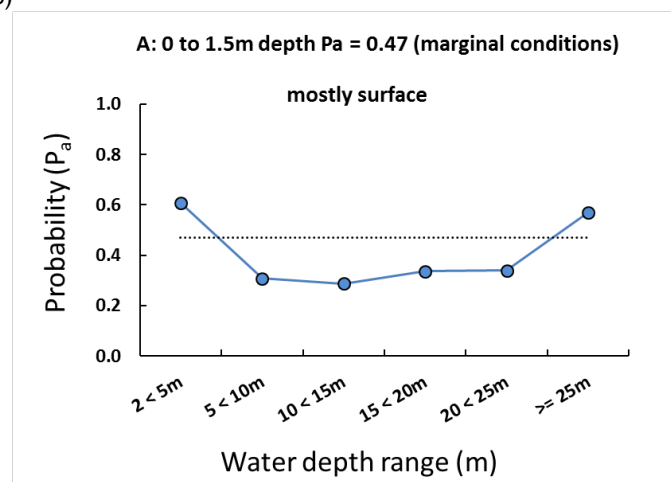


Figure A4 a & b. Trend in the probability of dugongs being available for detection ( $P_a$ ) and water depth (m) for (a) Optimal survey conditions in the viewing depth range 0 to 2.5m and for two habitats (seagrass & offshore) and, similarly for (b) Marginal survey conditions in the viewing depth range 0 to 1.5m. Data were reconstructed from Figure 2 in Hagihara *et al.* (2014). The constant dotted line are estimates of constant availability bias ( $P_a$ ) derived by Pollock *et al.* 2006.

Table A7. Summary of the mean probabilities of dugongs being available for detection ( $P_a$ ) and their associated Standard Errors (SE) in water  $\leq 20\text{m}$  bathymetry, for two viewing depths (0 - 1.5m & 0 – 2.5 m) and two habitats (seagrass & offshore). From Hagihara *et al.* (2014), see Figure A4 a-d.

Habitat	0 to 1.5 m		0 to 2.5 m	
	$P_a$	SE	$P_a$	SE
Seagrass	0.44	0.02	0.65	0.03
Offshore	0.38	0.01	0.69	0.01
Mean	0.41	0.01	0.67	0.02

Table A8. Estimates of availability probabilities ( $P_a$ ) and associated correction factors ( $Ca \pm SE$ ) to correct Kimberley observed counts to estimates of absolute counts for each turbidity rank (1-4) out to the 20m bathymetry line (data from Hagihara *et al.* 2014).

Turbidity rank	$P_a$	Ca	SE (Ca)
1	0.59	1.69	0.07
2	0.59	1.69	0.07
3	0.39	2.56	0.05
4	0.39	2.56	0.05

Table A9. Summary of the different analysis methods to estimate dugong abundance used in this report, and the pros and cons of each approach.

Analysis method & purpose (models)	Source	Perception CF	Availability CF	Error estimation procedure	Pros & cons
Stable and reliable index of abundance.	Bayliss 1986 after Caughley & Grigg (1981) and Caughley & Grice (1982).	Yes – based on groups or sighting entities.	No – the unseen proportion under the water was not addressed.	Ratio Method for unequal length transects.	Suitable for monitoring trends in average annual population rate of increase & assessing regional threats.
Absolute numbers.	Bayliss & Freeland (1986) & Marsh & Sinclair (1989a)	Yes – as for 1.	Yes – based on proportion observed on surface in optimal clear shallow waters.	Ratio Method.	Proportion (~18%) of surface dugongs is assumed constant & applicable under all survey conditions. At the time this generality was untested. Provides a more accurate index of absolute numbers but was untested.
Absolute numbers, new simulation method to estimate sample errors.	Pollock <i>et al.</i> (2006) to address influence of turbidity & sea state on visibility. See also O'Brien (2007) w.r.t. issues with the error estimation procedure.	Yes – for individuals.	Yes – based on field experiments to address optimal & sub-optimal survey conditions w.r.t. sea state & turbidity,	Monte Carlo simulation & estimation of Variance Inflation Factor (VIF) to address clumped dispersion of transect counts & multicollinearity due to unequal length transects.	Proportion of dugongs available for detection assumed constant for each set levels of survey condition w.r.t. sea state and turbidity (although data were available to develop extrapolation equations for variable conditions but not used). Reduction of errors (variation between transect sample units) using a VIF is spurious for values > 8, a characteristic of most aerial survey data. This method is re-assessed here.
Absolute numbers.	Hagihara <i>et al.</i> (2014). Examined influence of survey condition, habitat and water depth on diving behaviour & hence availability bias.	Not specifically, assumed confounded with Cp. Can use Cp of Pollock <i>et al.</i> (2006).	Yes – specifically addressed water depth & habitat variation.	Not addressed.	Likely the most accurate estimate of availability bias (Pa) due to significantly larger sample size of animals used to obtain dive information under a range of conditions.
Reliable “minimum” population estimate for Kimberley & new method to derive sample errors.	This report, uses Hagihara <i>et al.</i> (2014) availability bias corrections being best available.	Yes – Cp of Pollock.	Yes – mean values of Ca for water depth < 20m (the outer boundary of the Kimberley survey).	Derives probability density function (pdf; Exponential) & uses Monte Carlo simulation to replace VIF.	Uses most updated corrections for availability bias & builds on the method of Pollock <i>et al.</i> New error estimation procedure developed & is more reliable than Pollock <i>et al.</i> but not significantly greater than the early Ratio Methods developed by Caughley & Grigg (1881).

## Appendix 5. Estimates of dugong abundance using different approaches outlined in Table A9 to compare historical data in other regions

Table A10. Method 1. Estimates of population size ( $\hat{N} \pm \text{SE}$ ) and density ( $\hat{D} \pm \text{SE km}^{-2}$ ) of dugongs in the Kimberley region (Sept/Oct 2015). The Bayliss (1986) method to estimate perception bias ( $C_p$ ) from double counts of groups/sighting entities was used to standardise survey-specific variability. No corrections were made for availability. The ratio method was used to estimate sample errors.

Block	$\hat{N}$	SE (N)	% SE	$\hat{D}$	SE (D)
3	766	207	27.1	0.46	0.17
4	508	149	29.3	0.32	0.12
5	1,572	386	24.6	1.43	0.46
6	2,707	596	22.0	2.44	0.74
7	420	188	44.7	1.00	0.50
8	452	184	40.8	1.04	0.47
9	194	183	94.5	0.35	0.34
<b>Total</b>	<b>6,620</b>	<b>(<math>\pm 820</math>)</b>	<b>12.4</b>	<b>0.20</b>	<b>(<math>\pm 0.02</math>)</b>

Table A11. Method 2. Estimates of population size ( $\hat{N} \pm \text{SE}$ ) and density ( $\hat{D} \pm \text{SE km}^{-2}$ ) of dugongs in the Kimberley region (Sept/Oct 2015). The Marsh and Sinclair (1989a) method to estimate availability bias ( $C_a$ ) from the proportion of dugongs at the surface was used (and Bayliss & Freeland 1989), and the Ratio Method (Bayliss 1986) used to estimate sample errors.

Block	$\hat{N}$	SE	% SE	$\hat{D}$	SE
3	3,692	1,341	36.3	0.46	0.17
4	2,449	935	38.2	0.32	0.12
5	7,579	2,430	32.1	1.43	0.46
6	13,049	3,951	30.3	2.44	0.74
7	2,026	1,022	50.4	1.00	0.50
8	2,180	997	45.7	1.04	0.47
9	936	906	96.8	0.35	0.34
<b>Total</b>	<b>31,911</b>	<b>(<math>\pm 5,201</math>)</b>	<b>12.4</b>	<b>0.96</b>	<b>(<math>\pm 0.17</math>)</b>

Table A12. Combination of Methods 1 and 3. Estimates of population size ( $\hat{N} \pm SE$ ) and density ( $\hat{D} \pm SE \text{ km}^{-2}$ ) of dugongs in the Kimberley region (Sept/Oct 2015). The Pollock *et al.* (2006) Ca values were used, the corrections for perception bias (Cp) was applied to individuals and the Ratio Method (Bayliss 1986) used to estimate sample errors.

Block	$\hat{N}$	SE	% SE	$\hat{D}$	SE
3	1,525	522	34	0.19	0.06
4	1,396	416	30	0.18	0.05
5	2,731	1,185	43	0.51	0.22
6	3,260	827	25	0.61	0.15
7	780	374	48	0.38	0.18
8	658	297	45	0.31	0.14
9	236	226	96	0.09	0.09
<b>Total</b>	<b>10,585</b>	<b>(<math>\pm 3,847</math>)</b>	<b>15.8</b>	<b>0.32</b>	<b>(<math>\pm 0.05</math>)</b>

Table A13. Combination of Methods 1 and 4. Estimates of population size ( $\hat{N} \pm SE$ ) and density ( $\hat{D} \pm SE \text{ km}^{-2}$ ) of dugongs in the Kimberley region (Sept/Oct 2015). The Hagihara *et al.* (2014) mean Ca values were used for turbid water < 20m depth, the Cp perception corrections applied to individuals and the Ratio Method (Bayliss 1986) used to estimate errors.

Block	$\hat{N}$	SE	% SE	$\hat{D}$	SE
3	1,831	476	26	0.23	0.06
4	1,691	415	25	0.22	0.05
5	3,093	1,173	38	0.58	0.22
6	3,830	545	14	0.72	0.10
7	921	401	44	0.45	0.20
8	620	243	39	0.29	0.12
9	222	207	93	0.08	0.08
<b>Total</b>	<b>12,208</b>	<b>(<math>\pm 3,461</math>)</b>	<b>12.5</b>	<b>0.37</b>	<b>(<math>\pm 0.05</math>)</b>

**Appendix 6. Ancillary survey data – sightings and abundance “hotspot” maps of snubfin dolphins, other dolphins and turtles (mostly large greens). Sightings of identified dolphins and humpback whales are also presented.**

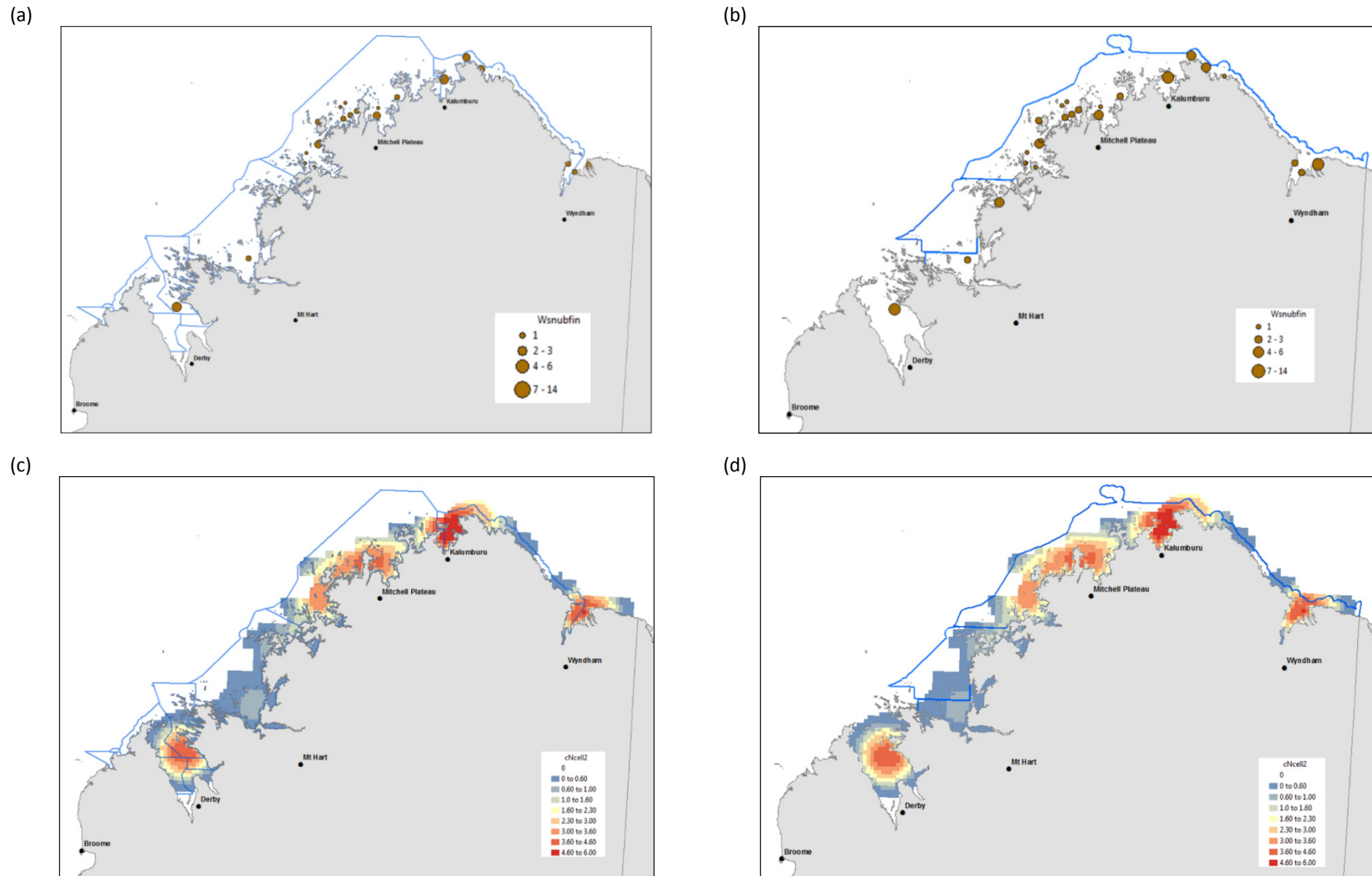
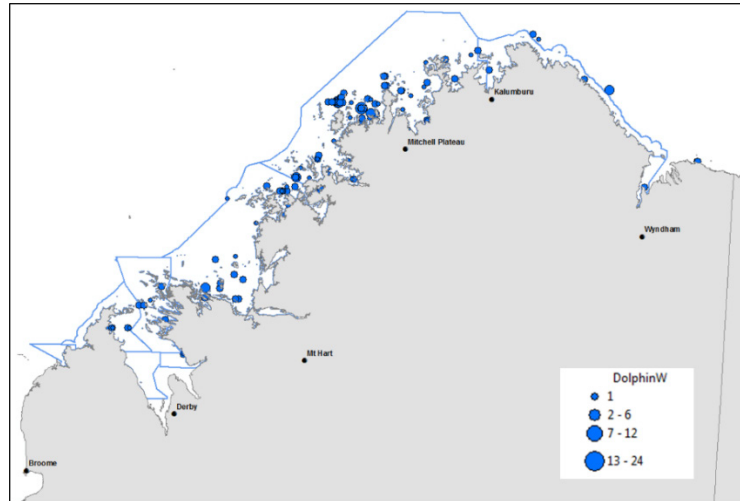
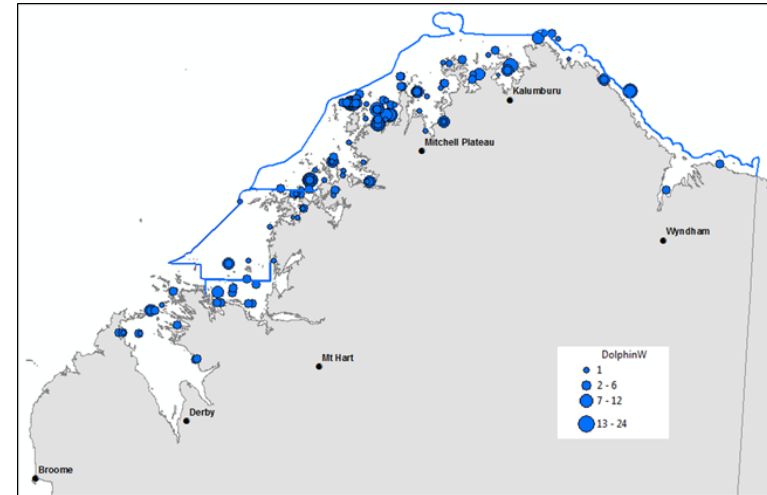


Figure A5 a-d. SNUBFIN DOLPHIN sightings on and off transects (weighted for effort) for (a) Native Title sea country and (b) proposed and existing marine reserve areas. Relative abundance “hotspots” mapped by Kernel smoothing (extrapolation) of observed data across the 5 km survey grid for (c) Native Title sea country and (d) proposed and existing marine reserve areas. Numbers per cell are relative indices of abundance only uncorrected for survey biases, not absolute estimates, but can be considered minimum estimates.

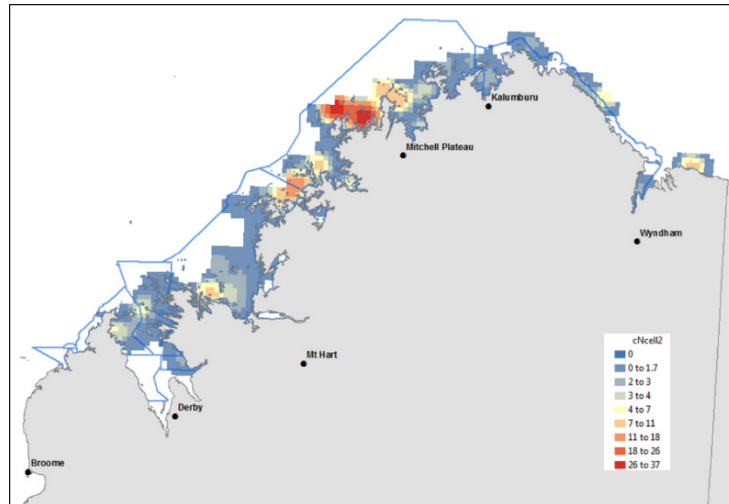
(a)



(b)



(c)



(d)

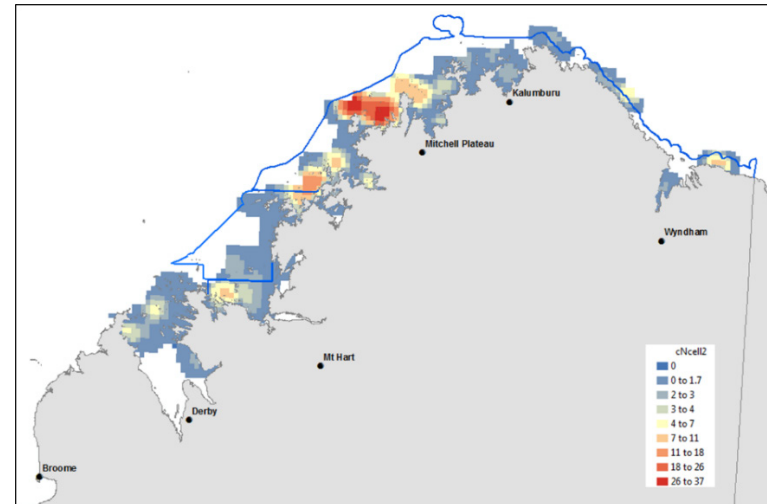


Figure A6 a-d. OTHER DOLPHIN (besides snubfin) sightings on and off transects (weighted for effort) for (a) Native Title sea country and (b) proposed and existing marine reserve areas. Relative abundance “hotspots” mapped by Kernel smoothing (extrapolation) of observed data across the 5 km survey grid for (c) Native Title sea country and (d) proposed and existing marine reserve areas.

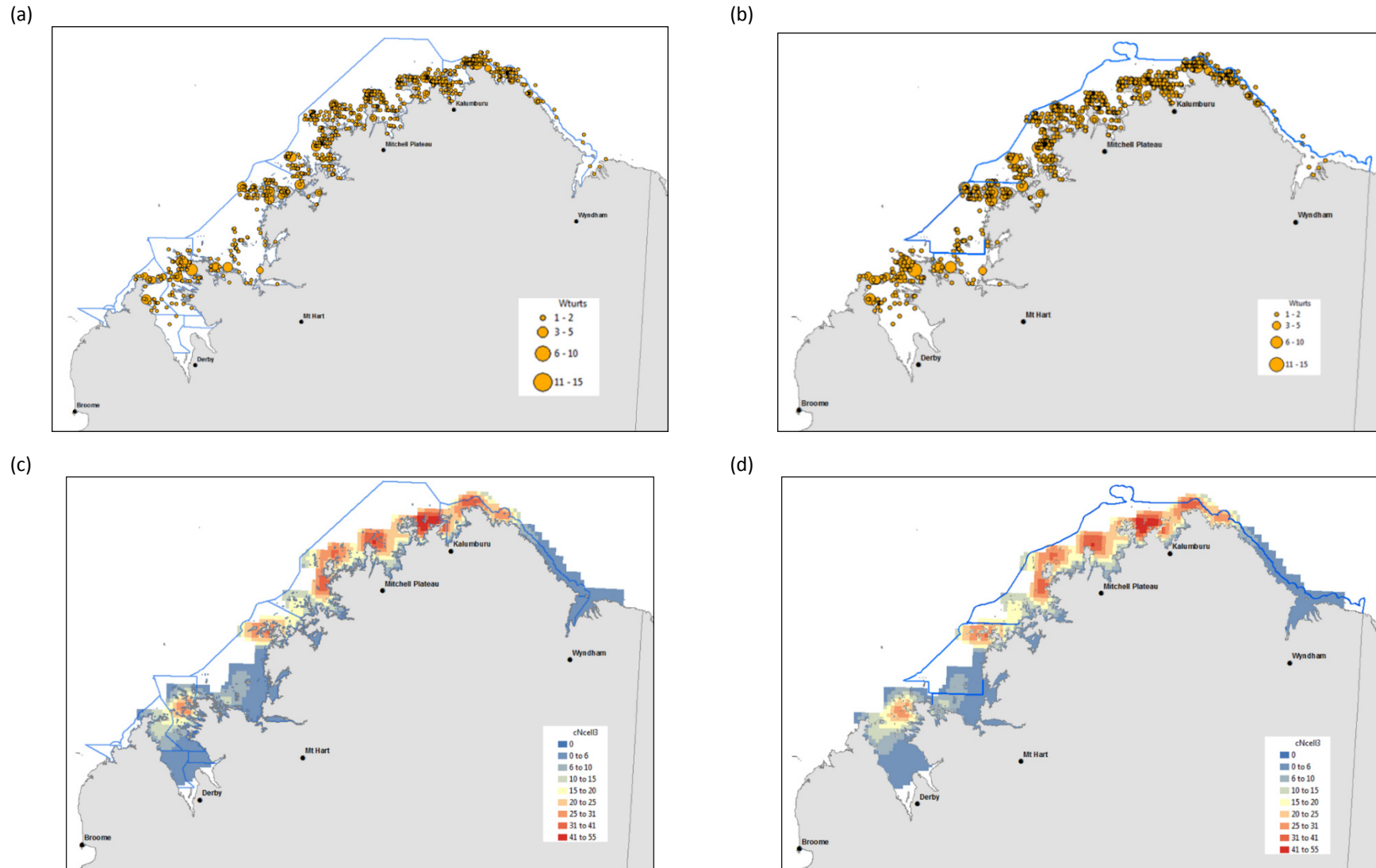
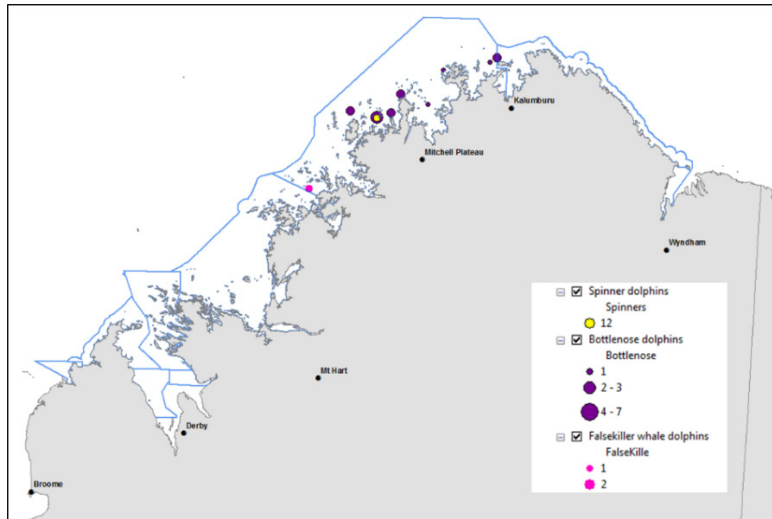


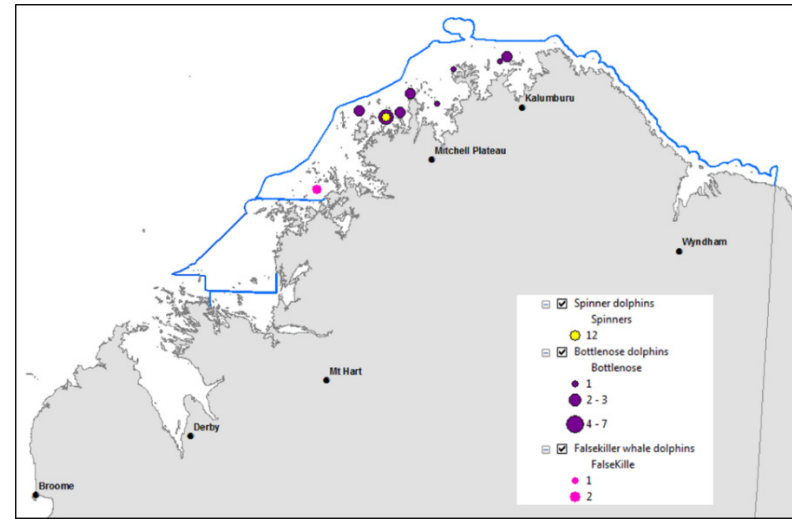
Figure A7 a-d. TURTLE sightings on and off transects (weighted for variable effort; mostly large greens) for (a) Native Title sea country and (b) marine reserve areas. Relative abundance “hotspots” mapped by Kernel smoothing (extrapolation) of observed data across the 5 km survey grid for (c) Native Title sea country and (d) proposed and existing marine reserve areas. Numbers per cell are estimates of abundance uncorrected for perception or availability survey biases, hence they are relative indices of abundance only but can be considered minimum

estimates.

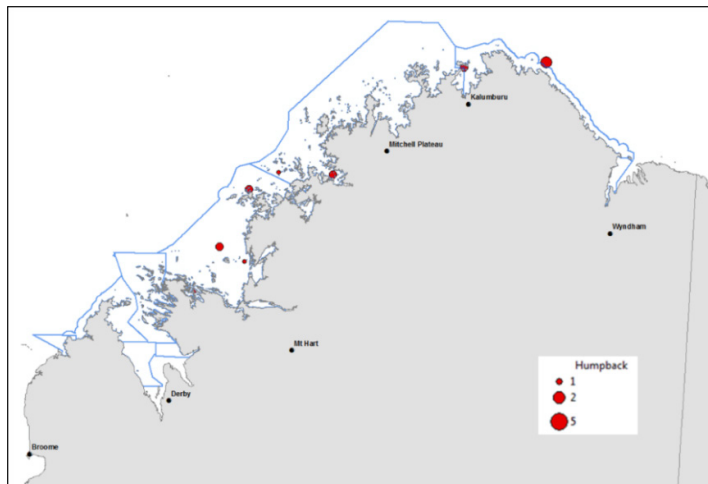
(a)



(b)



(c)



(d)

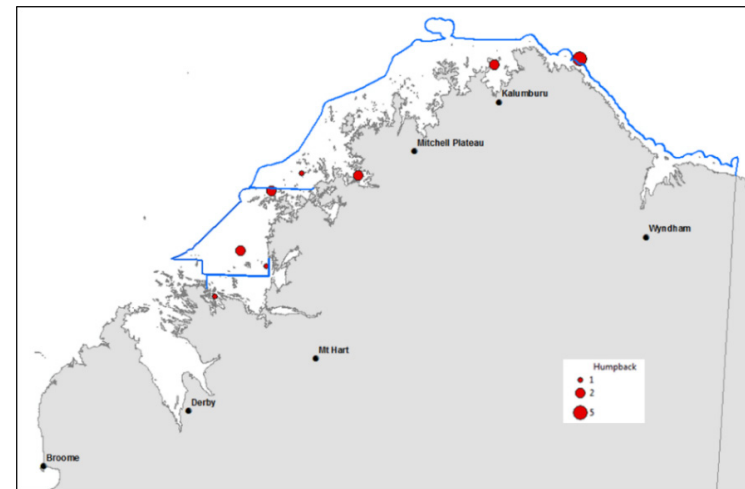


Figure A8 a-d. Sightings of bottlenose dolphins, spinner dolphins and false killer whale dolphins on and off transects (not weighted for effort), and (c & d) humpback whale sightings, for Native Title sea country and marine reserve areas respectively