Dugong population trends across two decades in Shark Bay, Ningaloo Reef and Exmouth Gulf.

Amanda J. Hodgson [a]
Helene Marsh [b]
Nick Gales [c]
Dave Holley [d]
Ivan Lawler [b]

[a] Centre for Marine Studies, University of Queensland, St Lucia QLD 4072
[b] School of Earth and Environmental Sciences, James Cook University, Townsville QLD 4811
[c] Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston TAS 7050
[d] Department of Environment and Conservation, Shark Bay District Office, Denham WA 6357

Please address any correspondence to:

Amanda Hodgson
hodgson.aj@gmail.com
Address: CMS, University of Queensland, St Lucia QLD 4072

EXECUTIVE SUMMARY

- Shark Bay supports a globally significant population of dugongs which are arguably the best protected of all extant populations. Exmouth Gulf and Ningaloo Reef also support a significant population of dugongs.

- A dugong aerial survey monitoring program has seen five surveys conducted since 1989 in Shark Bay and four in Exmouth/Ningaloo. These surveys have suggested that the Shark Bay population has remained relatively stable apart from an apparent increase in 1999 following a cyclone that destroyed seagrass beds at Exmouth/Ningaloo, and an apparent decline in dugongs in this latter region. From this, Gales et al. (2004) suggested that dugongs move between the two regions.

- The current aerial survey program follows the now outdated *Shark Bay Marine Reserves Management Plan 1996-2006* (CALM 1996). In light of the need to review this Plan, and the current development of the *Dugong Management Program* for dugongs in Western Australia, the first objective of this report was **to obtain a reliable index of the relative density of dugongs throughout Shark Bay, Ningaloo and Exmouth Gulf to compare among all surveys as a basis for assessing population changes and trends.**

- There have been recent improvements in the methods used to correct the raw sightings of dugongs for unseen animals and to produce a more robust estimate of dugong abundance (Pollock et al. 2006). Estimates using this technique have only been calculated from the latest (2007) aerial survey of Shark Bay/Exmouth/Ningaloo, however the necessary data were available to also calculate new estimates for Shark Bay in 2002. Thus the second objective of this project was **to provide a more robust abundance estimate of the number of dugongs in the Shark Bay than previously obtained from the 2002 aerial survey and indexes of density for Shark Bay from the 2002 and 2007 data.**

- The new estimate calculated for the 2002 aerial survey was 9153 ± 1925 se. This estimate is lower than that presented in Holley et al. (2006) of 11021 ± 1537 se calculated using the Marsh and Sinclair (1989) method. However, it is similar to that calculated from the 2007 survey using the Pollock et al. (2006) method (9347 ± 1204 se). These new estimates are the most robust estimates that we can currently produce and should be the estimates upon which management decisions be based and to which all future surveys be compared.

- For Shark Bay, there were no significant differences in: (1) the index of relative dugong density (according to the Marsh and Sinclair method) among all survey years averaged within blocks or over all blocks in Shark Bay, (2) the index of relative dugong density (according to the Pollock et al. method) in 2002 and 2007 either averaged within blocks or over all blocks in Shark Bay, (3) the index of relative dugong density (according to the Pollock et al. method) in 2002 and 2007 among blocks averaged across years. However, the relative density index (according to the Marsh and Sinclair method) varied significantly among blocks in Shark Bay.

- For Exmouth/Ningaloo, there were no significant differences in relative dugong densities (according to the Marsh and Sinclair method) (1) among years averaged within blocks or over all blocks and (2) between the Exmouth and Ningaloo blocks averaged across years.

- The apparent changes in the dugong populations in the Shark Bay and Exmouth/Ningaloo regions following the 1999 cyclone in Exmouth were not reflected in the standardised comparisons of relative dugong densities. The large variation in the distribution of dugongs *within* blocks swamps the variation between blocks and across survey years. Therefore the data from the aerial surveys are not robust enough to detect subtle changes in the populations due to relatively small numbers of animals moving between the regions. However the data do suggest that at least in Shark Bay, the dugong population has remained stable since 1989.

- In Shark Bay, the block containing the eastern side of Dirk Hartog Island had consistently higher densities than more northern and southern blocks. This reflects the important winter habitat area for dugongs in this region. However the relatively arbitrary placement of block boundaries makes it difficult to use comparisons between blocks to determine the most important habitat areas within Shark Bay. This could better be determined by combining all aerial survey data to produce a dugong density spatial model.

- Given that comparisons between aerial survey density estimates across years are unlikely to show subtle changes in dugong populations resulting from small numbers of dugongs moving between habitat areas, future research in WA should incorporate other techniques such as satellite tracking and population genetics to investigate the interconnectedness between populations. Future research, including aerial surveys, needs to be expanded to incorporate possible important dugong habitats in the Kimberley region.

Recommendations:

1. That the biologically and logistically feasible spatial scale upon which to manage dugongs be investigated through population genetic techniques.

2. That satellite tagging programs be continued and expanded along the WA coastline to determine important habitat areas and movement between them.

3. That the program of aerial surveys in Shark Bay, Ningaloo Reef and Exmouth Gulf be continued, but extended to include dugong habitat northward of the Ningaloo-Exmouth region, to provide the basis for a spatial risk assessment of dugongs in WA.

4. That a spatially explicit dugong density model be developed for Shark Bay and the Exmouth/Ningaloo region from which, the conservation value of various habitats within the regions can be identified and spatial risk assessments can be conducted.

5. That future dugong research in northern Western Australia incorporates the early involvement of stakeholder groups to facilitate knowledge exchange with traditional Indigenous owners, co-payment by industry, and risk assessment of future developments.

CONTENTS

INTRODUCTION

The importance of Shark Bay Marine Park for the conservation of dugongs is one of the reasons for the World Heritage listing of the Bay. Globally, dugongs are classified as vulnerable to extinction (IUCN 2007), but the large population of dugongs (in the order of 10,000) in Shark Bay is arguably the best protected of all extant populations. In accordance with the *Shark Bay Marine Reserves Management Plan 1996-2006* (CALM 1996) the Marine Park is managed with an emphasis on protecting this species. In addition, dugongs in Shark Bay are isolated from the multiple impacts of urban development and are subject to low levels of indigenous hunting.

Five aerial surveys to determine dugong distribution and abundance within Shark Bay have been conducted within the past two decades (1989, 1994, 1999, 2002 and 2007). These surveys followed the priorities and strategies outlined for dugongs within the *Shark Bay Marine Reserves Management Plan 1996-2006* (CALM 1996) which aimed to conduct dugong distribution surveys at a minimum of five-year intervals and “implement a long-term population monitoring program for dugongs”. All surveys except that conducted in 2002 included the Exmouth Gulf and Ningaloo Reef Marine Park. This region also supports a significant population of dugongs. The *Management Plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area* (CALM and MPRA 2005) also identifies the need to undertake research to better understand the dugong population, distribution and habitat requirements in the reserves and the adjacent areas of the Exmouth Gulf and determine the current status of the dugong population in relation to historical levels. The Shark Bay dugong population were qualitatively linked to populations inhabiting the Exmouth-Ningaloo region following a decline in dugong numbers following a cyclone that destroyed seagrass beds in the Ningaloo-Exmouth region in 1999 and simultaneous apparent increases in dugong numbers in Shark Bay. Gales et al. (2004) suggested that the dugongs had moved in response to this seagrass loss.

The management plan for Shark Bay (CALM 1996) is now outdated and will eventually be superseded. A *Dugong Management Program* for the entire Western Australian coastline is also currently in review. In lieu of the need for updated objectives for management directed at the conserve dugongs, now is an appropriate time to assess dugong population trends using the five years of aerial survey data in the Shark Bay. A comparison of dugong densities among years should aid in determining whether current protection measures have been effective in maintaining the dugong population. Similar comparisons and assessments can be made for the Exmouth-Ningaloo region, and from these it may be possible to determine whether any statistically identifiable reduction in the population occurred following the 1999 cyclone (and subsequent increase in Shark Bay). Therefore the first objective of this report was:

> **To obtain a reliable index of the relative density of dugongs throughout Shark Bay, Ningaloo and Exmouth Gulf to compare among all surveys as a basis for assessing population changes and trends.**

There have been recent improvements in the methods used to correct the raw sightings of dugongs for unseen animals and to estimate dugong abundance (Pollock et al. 2006). Both the methods described by Marsh and Sinclair (1989) and Pollock et al. (2006) allow estimates to be calculated using correction factors that account for availability bias (dugongs within the survey area but not ‘available’, i.e., not at the surface or visible) and perception bias (dugongs available but not detected by the observer). In the Marsh and Sinclair (1989) method, a correction factor for availability bias is calculated by standardising the proportion of animals classified by observers as ‘at the surface’ against the corresponding proportion in an earlier survey in shallow, clear water where all dugongs could be seen. This method assumes that the proportion of dugongs at the surface at any one time is independent of factors such as water depth, temperature and variation in dugong behaviour. Pollock et al. (2006) combined data obtained using two independent methodologies to develop availability probabilities for dugongs according Beaufort sea state and turbidity: (1) analysis of dive profiles from live animals fitted with timed depth recorders, and (2) observing the depth at which dugong models could be seen from the air (at the standard survey height) in various conditions. This information enabled the proportion of time dugongs spend within the upper section of the water column within which they are visible, and thus the proportion of time they are 'available' to be counted, to be estimated according to the environmental conditions at each sighting. Therefore the Pollock et al. (2006) method is superior because it accounts for the spatial heterogeneity in turbidity and Beaufort sea state conditions throughout the survey area, which affect the availability of dugongs. The Marsh and Sinclair method (1989), (1) averages these conditions throughout the survey area, (2) relies on observers to distinguish whether dugongs are at the surface or not, which observers find difficult.

The data from the 2007 survey were analysed using the improved method as well as the original method (according to Marsh and Sinclair 1989), with the two yielding quite different estimates. Considering the significant improvements of the new method, estimates using this technique are now considered the most robust standardised relative abundance estimates. Other than in 2007, the necessary environmental data needed to use the new method were only collected during the 2002 survey of Shark Bay. Re-analysis of the 2002 survey data and population estimate allows more direct and accurate comparisons with the most recent estimates (2007). We could then compare the new density estimates across these two years for further confirmation of whether the dugong population is stable within Shark Bay. Thus the second objective of this project was:

> **To provide a more robust abundance estimate of the number of dugongs in the Shark Bay than previously obtained from the 2002 aerial survey and indexes of density for Shark Bay from the 2002 and 2007 data.**

METHODS

Study area

Shark Bay is situated midway along the coast of Western Australia (25°30'S, 113°30'E). The Bay is 13,000 km^2 in area and divided into two embayments separated by the Peron Peninsula. Shark Bay is afforded a high level of protection as both a Marine Park and a World Heritage Area (WHA). One of the values for which the Bay was nominated as a WHA are the large expanses of seagrass meadows (4,000 km^2) and diversity of seagrass species (12 species) within the area (Walker 1989). The area experiences mean annual temperatures of 17-27°C and limited rainfall (mean 224 mm per year). The subsequent low freshwater input into the Bay has produced three salinity zones: oceanic, metasaline and hypersaline (enclosed sections such as south-eastern bay, CALM 1996).

Ningaloo Reef is 200 km north of Shark Bay (22°30'S,113°48'E), and extends for 260 km along the western shore of the Cape Range Peninsula, which encloses Exmouth Gulf (22°0'S,114°24'E). The reef encloses a narrow lagoon extending 200 m to 6 km from the shoreline, with an average depth of 4 m. The reef and lagoon form the Ningaloo Reef Marine Park. Mean temperatures range between 19 and 29°C, and again, the area experiences a low mean rainfall of 296 mm per year. Low runoff into the reef lagoon results in relatively clear waters. In contrast, Exmouth Gulf contains fringing mangroves, mudflats, rock pavements and soft-bottom habitats, producing turbid waters (Preen et al. 1997).

Aerial surveys

Five aerial surveys have been conducted in Shark Bay: July 1989, June 1994, July 1999, February 2002 and June 2007. Surveys of Exmouth Gulf and Ningaloo Reef were conducted at the same time for all years except 2002. All surveys followed the same survey design to provide dugong population estimates for approximately the same areas. Shark Bay was divided into 7 blocks, while in Exmouth/Ningaloo, the Gulf represented one block and the Reef represented the second block (Figure 1). The survey methods follow those developed by Marsh and Sinclair (1989; 1989), with the two latter surveys also incorporating methods described in Pollock et al. (2006). Details specific to each survey can be found in Marsh et al. (1994), Preen et al. (1997), Gales et al. (2004), Holley et al. (2006) and Hodgson (2007).

A Partenavia 68B aircraft was used, with the survey team consisting of four dedicated observers (two on each side of the aircraft) and a survey leader. Straight-line parallel transects were flown in an east-west direction at intervals of 2.5 nm (4.6 km; see Appendix 2 for maps of transects flown each year). The transect strip width on each side of the aircraft was 200 m, providing a net transect strip width of 400 m. The transect strip was split into four equal zones and the outside of the transect strip and zones were delineated using marker poles attached to pseudo wing-struts (Marsh and Sinclair 1989). These markers were calibrated on the ground to account for the eye height of individual observers. The surveys were flown at a height of 450 ft (137 m) ASL, providing a survey intensity of 9-10%.

For each survey, the team leader recorded the sightings called by the primary observers (one on each side of the aircraft) while the sightings of all four observers were also recorded onto a two-track audio recording system via aviation headsets connected to two intercoms. Each intercom was connected to a separate track of a two-track digital voice recorder. This arrangement allowed the sightings of the two observers on each side of the aircraft to be independent and compared to determine perception bias as explained below.

For each dugong group sighted in all surveys observers recorded the total number of animals visible (including number of calves), along with the number of animals at the surface, and position in the transect (low – very high). In 2002 and 2007 observers also noted the turbidity for each sighting (see scale in Appendix 1) which allowed the availability bias to be calculated using the Pollock et al. (2006) method.

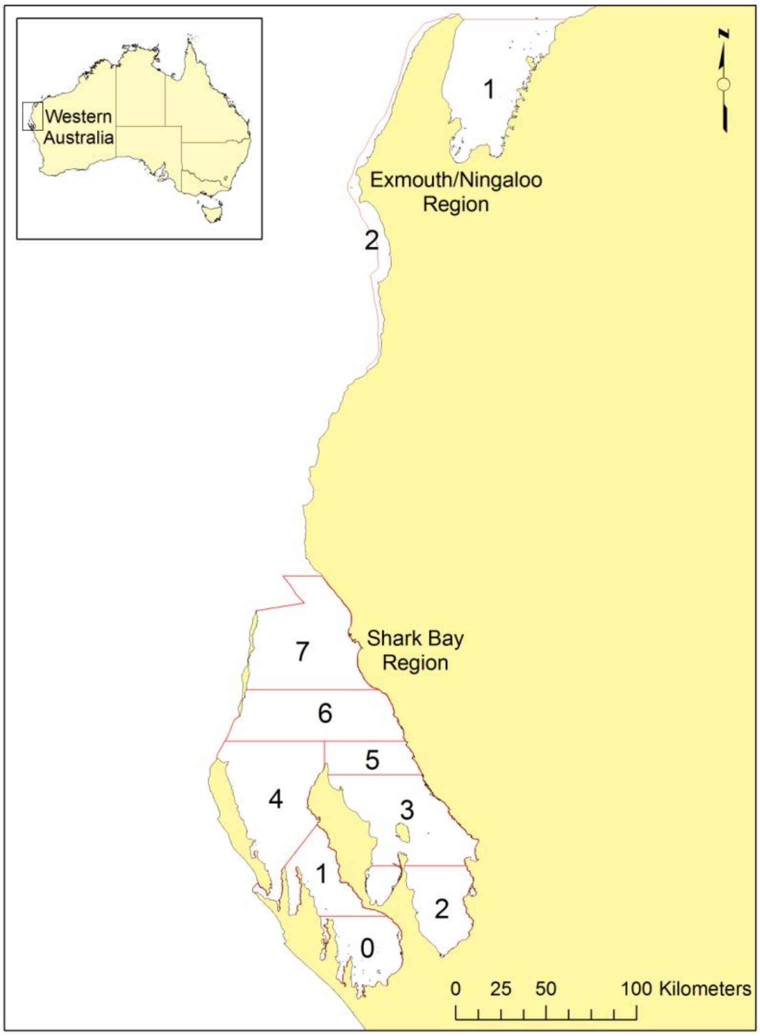


Figure 1. The two study regions covered by aerial surveys, including the outline of blocks in each region. Block 1 in the Exmouth/Ningaloo region is Exmouth Gulf and Block 2 covers the extent of Ningaloo Reef.

The survey leader entered data on environmental conditions at the beginning of each flight (cloud cover, cloud height, wind speed, wind direction and air visibility) and each transect (cloud cover). Every few minutes during each transect, and whenever conditions changed, the survey leader recorded Beaufort sea state, and glare on each side (scored by the observers, scales in Appendix 1). This latter data also included turbidity in 2007.

Re-estimating the dugong population for 2002

Dugong sighting data collected in 2002 were used to calculate an abundance estimate according to the Pollock et al. (2006) method for correcting for unseen animals due to availability and perception bias' and producing error estimates. To estimate availability bias (dugongs not being visible or 'available' to be counted), each dugong sighting was assigned an availability class (1-8) according to the water turbidity and Beaufort sea state at the location of the sighting, and the associated availability probability estimates provided by Pollock et al. (2006) were used to correct for the number of dugongs missed at that location due to them being 'unavailable'.

A mark-recapture model was used to estimate the proportion of the 'available' dugongs that are actually counted by the observers (Marsh and Sinclair 1989; Pollock et al. 2006) to account for perception bias. Dugong groups were "marked" when seen by one observer and then "recaptured" when seen by both. These data were modelled to determine whether the probably of an available dugong being detected was conditional on the observer, experience (primary or secondary observers), or side (port or starboard) using the MARK program (White and Burnham 1999). The perception probabilities used for each observer were those provided by the model that best fit the data according to Akaike's Information Criterion (AIC), which corrects for small sample bias. The probability that a dugong would be detected by at least one observer for each side of the aircraft was:

$$\hat{P}_d = 1 - \left(1 - \hat{P}_1\right)\left(1 - \hat{P}_2\right)$$

where $\hat{P}_1$ is the perception probability obtained for the primary and $\hat{P}_2$ the secondary observers (i = 1,2).

The abundance estimate was calculated as per Pollock et al. (2006), by applying the Horvitz-Thompson population estimator for each survey block:

$$\hat{N} = \sum_{j=1}^{n} \left[1/\hat{P}_j\right]$$

where n is the number of dugongs counted within the survey and $\hat{P}_j$ is:

$$\hat{P}_j = P_b \hat{P}_{aj} \hat{P}_{dj} .$$

The above formula corrects each sighting for the proportion of the survey area sampled (P_b), the probability of a group of dugongs (j) being available ($\hat{P}_{aj}$) and being detected given that it was available ($\hat{P}_{dj}$).

Standard errors were obtained using a Monte Carlo simulation method as detailed in Pollock et al. (2006).

All dugong groups containing more than 10 individuals were excluded from the above analysis and added to the final population estimate (Norton-Griffiths 1978).

Comparison of sighting conditions

During the 2007 survey, sighting conditions (i.e. Beaufort sea state and turbidity) were recorded randomly (approximately every 2 min) along each transect line. From these data we calculated the proportion of the survey conducted under each of the eight sighting condition categories for which Pollock et al. (2006) provide availability probabilities. In 2002 only Beaufort sea state was recording at random intervals along the transect, so we used the turbidity data recorded for each animal sighting to determine the proportion of the survey conducted under each sighting condition category.

To determine whether sighting conditions were different between the two years, we compared the total records of sighting condition categories in each year using a chi square test.

Density comparisons among years

For each survey, the relative density of dugongs per transect was estimated according to the corrected number of dugongs per transect following the Marsh and Sinclair method (1989) divided by the area of the transect (transect length multiplied by transect width of 400 m). For the 2002 and 2007 surveys we also calculated the relative density of dugongs per transect based on corrected estimates calculated using the Pollock et al. (2006) method.

The correction factors used each year, within each region, for the density estimates calculated using the Marsh and Sinclair method are provided in Table 1. Some differ from those published for each survey. For example, because the same team was used for all three regions in each of the surveys, the perception bias was calculated according to all sightings across regions, whereas in some published results perception bias was calculated separately for each region. The former method provides a more rigorous estimate of the perception bias as it uses the largest possible sample size, and there is no reason to expect the perception bias would differ between regions for the same observers.

The density estimates calculated according to the Pollock et al. method were corrected for the detection probability of 0.96 for all observers in 2002. In 2007 the Shark Bay team detection probabilities were 0.98 and 0.96 for the port and starboards teams respectively, and 0.93 for all observers of the Exmouth/Ningaloo team.

Table 1. Correction factors used to calculate estimates per transect for density comparisons among years (calculated according to the Marsh and Sinclair (1989) method)

Year	*Region*	*Group Size*	*CV*	*Perception*				*Availability*	*CV*
				Port	**CV**	**Starboard**	**CV**		
1989	Shark Bay	1.543	0.045	1.039 (tran 41-43, 1.286)	0.007	1.056 (tran 41-43, 1.300)	0.011	2.540	0.120
	Exmouth	1.390	0.061	1.039 (tran 41-43, 1.286)	0.007	1.056 (tran 41-43, 1.300)	0.011	2.400	0.231
	Ningaloo	1.390	0.061	1.039 (tran 41-43, 1.286)	0.007	1.056 (tran 41-43, 1.300)	0.011	1.091	0.464
1994	Shark Bay	1.450	0.039	1.043	0.010	1.097	0.017	3.331	0.115
	Exmouth	1.481	0.091	1.043	0.010	1.097	0.017	4.091	0.178
	Ningaloo	1.481	0.091	1.043	0.010	1.097	0.017	3.667	0.214
1999	Shark Bay	1.294	0.035	1.015	0.002	1.016	0.002	2.489	0.116
	Exmouth	1.208	0.070	1.015	0.002	1.016	0.002	0.000	0.000
	Ningaloo	1.208	0.070	1.015	0.002	1.016	0.002	0.923	0.658
2002	Shark Bay	1.218	0.036	1.067	0.010	1.035	0.006	2.301	0.121
2007	Shark Bay	1.519	0.095	1.023	0.004	1.045	0.008	3.129	0.113
	Exmouth	1.320	0.030	1.225	0.129	1.027	0.017	3.455	0.181
	Ningaloo	none							

Differences in relative dugong density estimates (calculated using the two methods) among survey years for the blocks surveyed in Shark Bay and for the Exmouth/Ningaloo blocks were examined by linear mixed-effects modelling. Blocks and years were treated as fixed effects, transects within blocks as a random effect. Mixed effects models were employed to estimate the random components of variance and to provide appropriate tests for differences between years, blocks and the block-year interaction. The parameters of these models were estimated by restricted maximum likelihood. The index of dugong density in each transect within blocks for each survey was the response. The data were log transformed (i.e., ln (y + 0.1)) to ensure a constant mean-variance relationship.

The statistical significance of the fixed effects was determined by simulation using Monte Carlo Markov Chains based on the estimated mixed-effects model parameters and using a uniform prior. Posterior distributions for the model parameters estimated with Monte Carlo Markov Chains were also used to estimate 95% credible intervals for these parameters.

RESULTS

New estimates for 2002

During this survey observers sighted 374 dugongs in groups of < 10 animals within the transect strips. The average group size for these sightings was 1.2 dugongs. An additional 313 dugongs were seen in herds of 12, 25, 32 and 244 in Block 3. The population estimate for the Shark Bay region using the Pollock et al. (2006) was 9153 ± 1925 se. This estimate is lower than that presented in Holley et al. (2006) of 11021 ± 1537 se calculated using the Marsh and Sinclair (1989) method. However, it is similar to that calculated from the 2007 survey using the Pollock et al. (2006) method (9347 ± 1204 se). The total estimates for each block are presented in Table 2, along with the comparative estimate from Holley et al. (2006).

There is a disproportionate difference in the two estimates for Block 3 relative to the other blocks when comparing the two estimates for 2002. This can be explained by the different methods for correcting for availability bias. As outlined above the new method accounts for heterogeneity in sighting conditions within the survey area by using an availability correction factor for each sighting based on the conditions at that point (Pollock et al. 2006). According to the old method a single availability correction factor is calculated for the whole survey area (Marsh and Sinclair 1989). Block 3 had particularly good sighting conditions with 71% of sightings occurring where the turbidity was classed as 1 (clear and shallow) and the associated probability of sighting animals was 1 (thus not needing correction for availability bias, Table 3). In Holley et al.'s (2006) calculations these sightings would have all been corrected for availability according to the bias calculated for the entire survey area, hence the higher estimate for Block 3.

Table 2. Estimates for each block of the Shark Bay survey region for 2002 using the Pollock et al. (2006) method and the method (Marsh and Sinclair 1989) used by Holley et al. (2006).

Block	New estimate (se)	Previous estimate (se)
0	2946 (1590)	2629 (780)
1	372 (188)	657 (115)
2	299 (162)	505 (171)
3	2823 (809)	4404 (881)
4	999 (400)	1245 (266)
5	324 (229)	278 (62)
6	677 (391)	634 (231)
7	712 (312)	970 (263)
Total	**9153 (1925)**	**11021 (1537)**

The sighting conditions did not differ between 2002 and 2007 ($\chi 2 = 6.80$, df = 7, $P > 0.05$; Table 3), suggesting that the turbidity levels recorded for each animal sighting were representative of the overall turbidity levels for the region. This also shows that turbidity levels are relatively similar in summer and winter, supporting the validity of comparisons between surveys undertaken at different times of the year.

Table 3. The availability of dugongs according to environmental conditions defined by Pollock et al. (2006) and the proportion of the surveys that took place within each of the eight classes.

Class	Water turbidity[1]	Beaufort sea state	Probability	Proportion of survey 2002	Proportion of survey 2007
1	1 - Clear & shallow	≤ 2	1	0.27	0.27
2	2 - Turbid & shallow	≤ 2	0.65	0.24	0.27
3	3 - Clear & deep	≤ 2	0.46	0.18	0.17
4	4 - Turbid & deep	≤ 2	0.47	0.00	0.04
5	1 - Clear & shallow	≥ 3	1	0.04	0.02
6	2 - Turbid & shallow	≥ 3	0.47	0.09	0.11
7	3 - Clear & deep	≥ 3	0.30	0.18	0.08
8	4 - Turbid & deep	≥ 3	0.47	0.00	0.04

[1] See Appendix 1 for full turbidity scale.

Comparisons between years

There were no significant differences in the index of relative dugong density (calculated according to the Marsh and Sinclair method) among survey years averaged within blocks or over all blocks in Shark Bay (Table 4, Figure 2A), but the relative density index varied significantly among blocks (Table 4, Figure 3A). The average block differences were due to the significantly higher density of dugongs in Block 4 compared to Blocks 1 and 2 (see Figure 1 and Appendix 2 for block areas)

The index of relative dugong density according to the Pollock et al. method did not vary significantly between the 2002 and 2007 Shark Bay surveys either averaged within blocks or over all blocks (Table 4, Figure 2B) and there were no significant differences among blocks averaged across years (Table 4, Figure 2B).

In the Exmouth/Ningaloo regions there were no significant changes in relative dugong densities among years averaged within blocks or over all blocks and there was no significant difference between the Exmouth and Ningaloo blocks averaged across years (Table 4, Figure 4).

The estimated credible intervals around the mean relative density estimates were large in most cases. These intervals reflect the small scale variation in dugong distribution within blocks rather than between blocks producing large variation in density index estimates among transects.

Table 4. Results of generalised linear mixed effects analyses examining variation in dugong densities among surveys and blocks within the Shark Bay and Exmouth/Ningaloo regions.

Source of variation	Num. DF	Denom. DF	MCMC P-value	Variance component
Shark Bay (using the Marsh and Sinclair (1989) method for all years)				
Block	7	87	**0.041**	
Among transects within blocks				$3.14e^{-11}$
Year	4	329	0.993	
Block x Year	28	329	0.994	
Residual among transect within block variation among years				$6.47e^{-02}$
Shark Bay (using the Pollock et al. (2006) method for 2002 and 2007)				
Block	7	89	0.973	
Among transects within blocks				$1.93e^{-11}$
Year	1	88	0.995	
Block x Year	7	88	0.859	
Residual among transect within block variation among years				$3.94e^{-02}$
Exmouth / Ningaloo (using the Marsh and Sinclair (1989) method for all years)				
Block	1	57	0.897	
Among transects within blocks				$4.1569e^{-11}$
Year	3	152	0.858	
Block x Year	3	152	0.833	
Residual among transect within block variation among years				$8.3138e^{-02}$

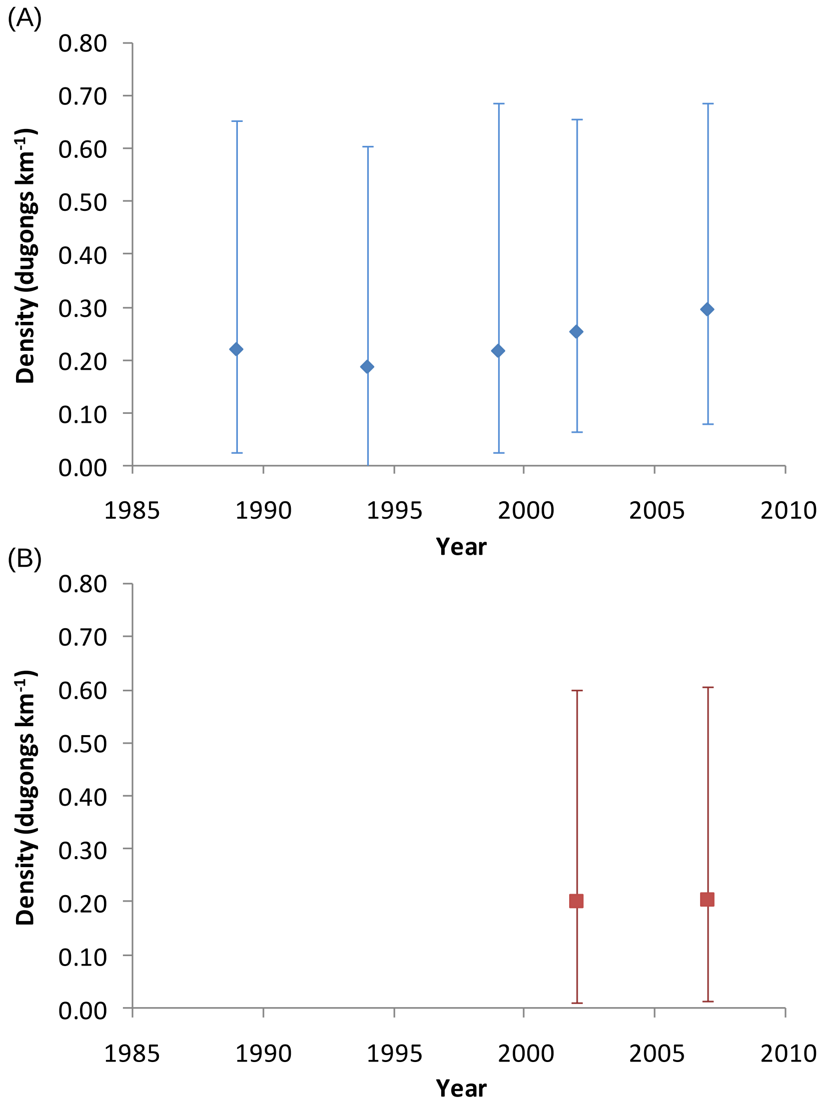


Figure 2. The estimated index of relative density dugong density (per km^2) over survey years in Shark Bay calculated according to (A) the Marsh and Sinclair (1989) method, and (B) the Pollock et al. (2006) method. Error bars represent 95% credible intervals.

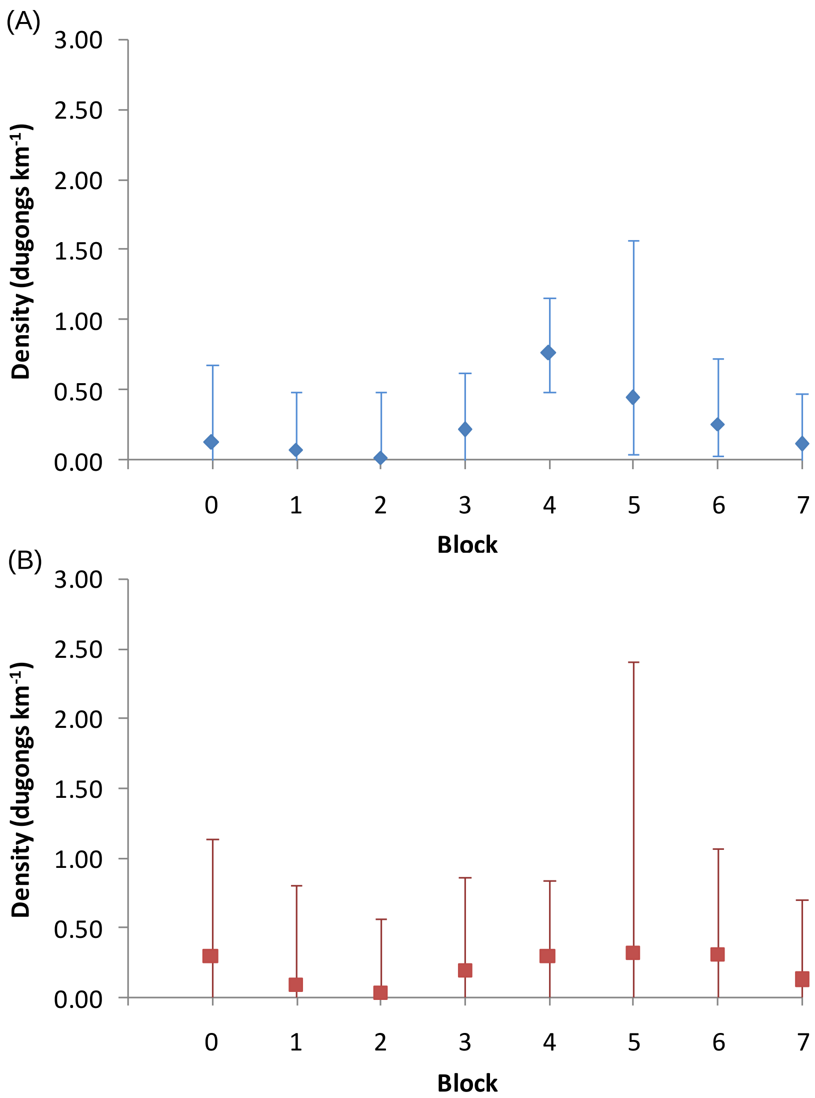


Figure 3. The estimated index dugong density (per km^2) over survey blocks in Shark Bay. Note that (A) represents relative densities across all five surveys calculated according to the Marsh and Sinclair (1989) method, while (B) represents relative densities for 2002 and 2007 according to the Pollock et al. (2006) method. Error bars represent 95% credible intervals.

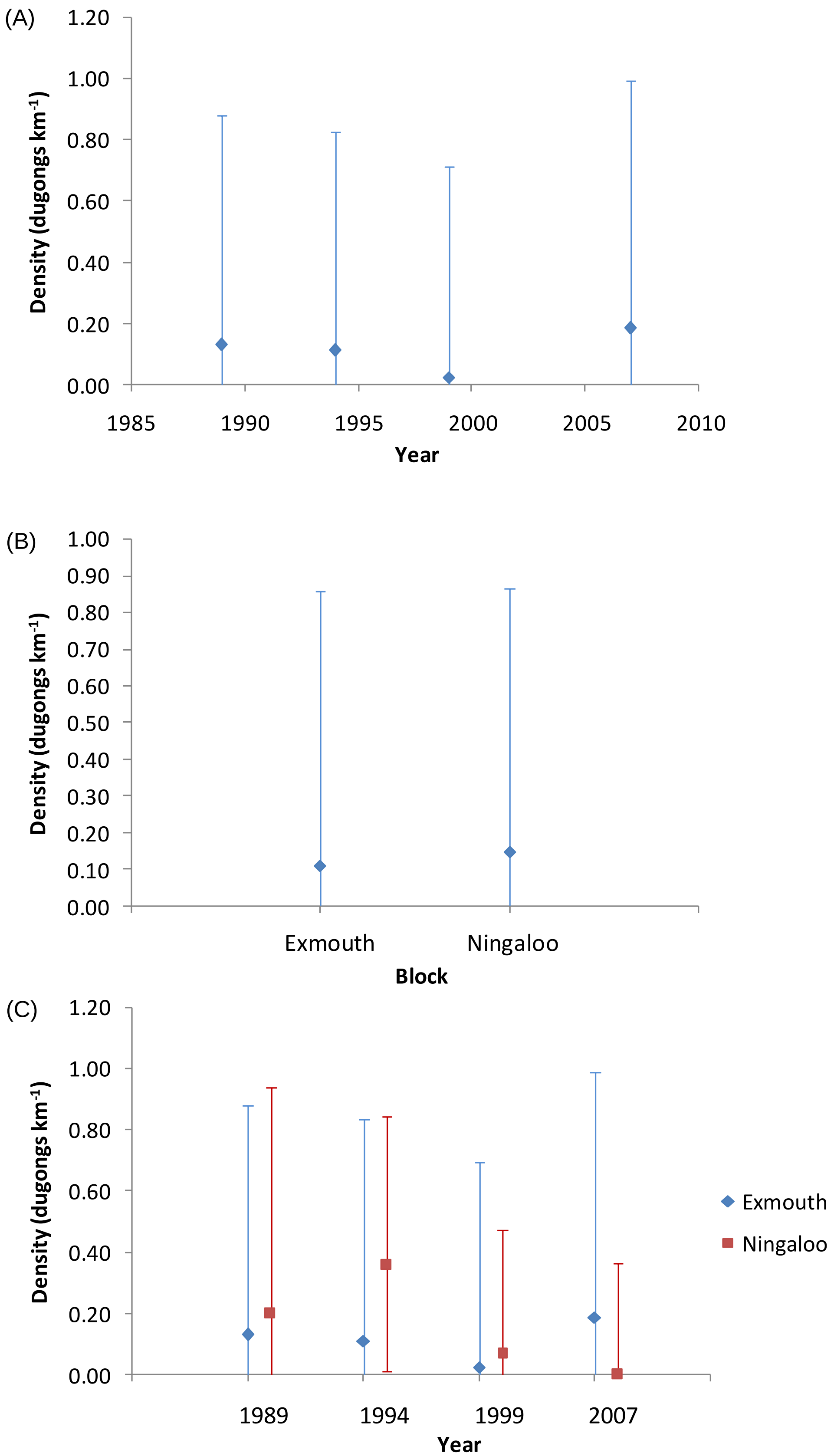


Figure 4. The estimated index of dugong density (per km^2) over (A) survey years averaged across blocks, (B) blocks averaged across years, and (C) survey years averaged within blocks in the Exmouth/Ningaloo regions. Error bars represent 95% credible intervals.

DISCUSSION

The most recent population estimates for Shark Bay

In Hodgson's (2007) report on the 2007 winter survey there was a discrepancy between the abundance estimates calculated according to the old Marsh and Sinclair (1989) method and the more robust Pollock et al. (2006) method. The former method provided a lower estimate than the original 2002 estimate while the latter (which is directly comparable) suggested that the population had increased. Having now calculated a new estimate for 2002 using the Pollock et al. method we can see that it too is lower than the original estimate produced by Holley et al. (2006). However, the estimates using the new method for 2002 and 2007 are similar across the two surveys (approximately 9,000 ± 2,000 se) suggesting no change in the population in the five years between the surveys (Figure 5). This qualitative assessment was substantiated by the statistical comparisons between years as discussed below. The new estimates are the most robust estimates that we can currently produce and should be the estimates upon which management decisions be based and to which all future surveys be compared.

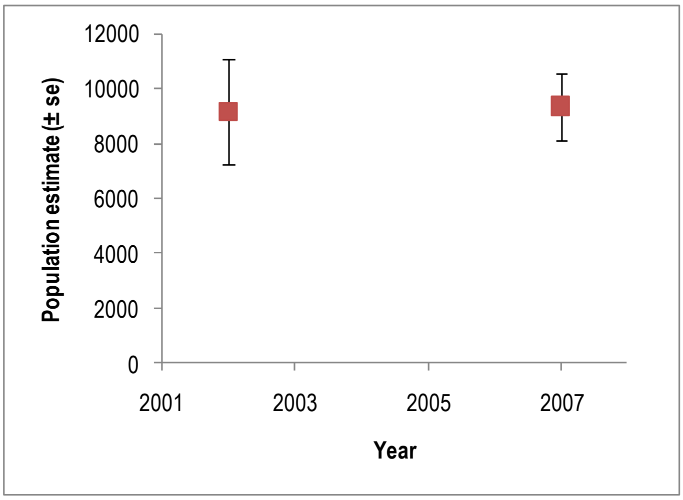


Figure 5. Population estimates for dugongs in Shark Bay produced using the new method for correcting for unseen animals (Pollock et al. 2006).

Changes in dugong abundance among years

The apparent variation in the dugong populations in the Shark Bay and Exmouth/Ningaloo regions across years as a result of the 1999 cyclone in Exmouth (Gales et al. 2004; Holley et al. 2006) were not reflected in our standardised comparisons of relative dugong densities. This was due to the large amount of variation in dugong density estimates for each transect and the large number of transects with densities of zero. This variation in the distribution of dugongs *within* blocks swamps the variation between blocks and across survey years (for distribution maps see Appendix 3). Therefore the data from the aerial surveys are not robust enough to detect subtle changes in the populations due to relatively small numbers of animals moving between the regions. The difficulty of detecting temporal change in numbers in the Exmouth/Ningaloo region is exacerbated by the relatively small population size.

We suggest that the lack significant change in dugong density estimates for all surveys in Shark Bay is reflective of a stable population inhabiting a well protected environment. There have been no major environmental or weather events to impact on the seagrass in the Bay and there are relatively few human impacts. On the other hand, the Exmouth/Ningaloo region has experienced a tropical cyclone which qualitatively reduced the dugong population in the region in 1999. The reason this was not reflected in our statistical comparison across years was again because of the large amount of variation in dugong densities among transects. The relatively sparse distribution of dugongs in both the Exmouth Gulf, and in particular the

Ningaloo Reef, blocks makes it particularly difficult to statistically compare among years in this region.

The challenges we have experienced here in detecting population trends are typical among marine mammal monitoring programs (Taylor et al. 2007). Our use of statistical models which account for random effects minimised, as much as possible, the influence of the relatively random nature of dugong movements between transects within blocks. Taylor et al. (2007) suggest that statistical methods such as these can increase power to detect trends. However, they also suggest that in some cases, the power to detect trends can only be increased by increasing survey effort. We suggest that our ability to monitor and understand trends in dugong populations in WA will be improved by expanding current satellite tracking programs and employing genetic techniques as discussed below which will provide more information on the connectedness between dugong populations along the WA coast. Future monitoring may also be enhanced by new unmanned aerial vehicle (UAV) technology which has the potential to reduce the time and funding required to conduct aerial surveys.

Dugong distribution within regions

The varied distribution of dugongs across surveys is also reflected in the fact that there were relatively minor differences between survey blocks (averaged across years) in Shark Bay according to the relative densities. The placement of the block boundaries in Shark Bay (see Figure 1 and Appendix 2 for maps of block boundaries) is arbitrary and the boundaries do not necessarily reflect different habitats, which limits our ability to detect differences in dugong densities between the blocks. However the results did show that Block 4, which includes the north eastern side of Dirk Hartog Island, has consistently higher densities than Blocks 1 (in the south of the western side of the Bay) and 7 (the most northern block, see Appendix 3 for distribution maps). These results reflect the fact that all but the 2002 surveys were conducted during winter and therefore Block 4 is an important winter habitat area for dugongs. We expected that the year/block interaction would have a significant effect on densities due to the different distribution of dugongs in the 2002 survey compared to all others. However, it appears that there isn’t a clear enough distinction between the distribution of dugongs in summer and winter for them to be statistically different. It should be noted that these comparisons do not include the large herds seen in Block 3 during the 2002 survey. Holley et al. (2006) clearly showed the importance of Blocks 1 and 3 for dugongs in summer and more summer surveys would allow for a more statistically robust comparison. However, summer surveys are particularly difficult logistically due to the high winds at that time of year.

In the Exmouth/Ningaloo region there were no significant differences between the Exmouth Gulf Block and the Ningaloo Reef Block and the year/block interaction effect was not significant. Although in 2007 only two dugongs were sighted along Ningaloo Reef compared to substantial numbers in Exmouth Gulf, the two Blocks have had relatively similar numbers in the previous three surveys.

The variation in dugong distribution between years within both regions makes it impossible to accurately assess the relative importance of various habitats within both the regions by simply looking at the raw distribution maps (Appendix 3). The best way to properly assess distribution is by producing a spatial model of the relative dugong densities. A spatially explicit dugong population model was produced for the Great Barrier Reef World Heritage Area (GBRWHA) using data from aerial surveys conducted since the mid 1980’s (Grech and Marsh 2007). From the model, the authors were able to identify areas of low, medium and high conservation value to aid management in prioritising conservation initiatives. Following this, Grech and Marsh (2008) assessed the relative risks of various human impacts throughout the region and the overall proportion of dugongs at risk from human impacts across the entire GBRWHA. As there is now a substantial amount of data from aerial surveys on the distribution of dugongs in the Shark Bay and Exmouth/Ningaloo regions, it would be timely and extremely valuable to produce a similar spatial model of dugong distribution throughout these two regions. We suggest that, if possible, separate models should be produced for the summer and winter distributions of dugong in Shark Bay to reflect the changing relative importance of different habitats in Shark Bay according to season. The Department of Environment and Conservation could then use these models to assess human impacts, and the relative risk of these impacts. This would aid in assessing risk and determining the appropriate location for proposed aquaculture or large scale development in the region.

Future Research: movements and populations in the north

Although not reflected in the analyses presented in this report, individual dugongs likely do move between the Shark Bay and Exmouth/Ningaloo regions as well as regions further north as suggested by Gales et al. (2004) and Holley et al. (2006). To date very few surveys have been conducted north of the Exmouth/Ningaloo region and therefore assessments of the relative importance of various dugong habitats along the WA coastline are limited to Shark Bay and Exmouth/Ningaloo. Only one survey of the Pilbara coast was conducted in 2000, producing a population estimate of approximately 2,000 (±400) relatively dispersed dugongs (Prince 2001). However, anecdotal evidence suggests there is a high density dugong population in the Kimberley region. Almost nothing is known of this population; the area has never been formerly surveyed and therefore almost no data exist on dugong abundance and distribution in the region. The Kimberley and Shark Bay dugong populations may be linked by the low density dugong population in the Pilbara/Exmouth/Ningaloo region, however, further satellite tracking of dugongs along with genetic studies as recommended by Hodgson (2007) would be the best way to determine the interconnectedness between these populations along the Western Australia coastline. Dugongs in the Pilbara and further north are likely more at risk of human impacts due to the current rapid expansion of mining (particularly oil and gas) in those regions and probable higher hunting rates, particularly in the south Kimberley region. A draft Dugong Management Program is currently in review, which should include a research and monitoring strategy for the whole WA coastline. This strategy should incorporate aerial surveys of the Pilbara and in particular, the Kimberley, regions.

RECOMMENDATIONS

RECOMMENDATION 1

That the biologically and logistically feasible spatial scale upon which to manage dugongs be investigated through population genetic techniques.

Recent genetic research using mitochondrial (maternally inherited) DNA shows regional differentiation between dugong populations along the east coast of Queensland (Blair et al. in review). A similar study of dugong populations along the WA coastline using both mitochondrial DNA and microsatellites would enhance our knowledge of the interconnectedness between these populations and provide a baseline for determining the best spatial scale at which to manage dugongs in WA. This genetic work could be conducted in conjunction with established dugong genetics programs at James Cook University, where the structure of dugong populations is being examined at both the Australia-wide and global scales (led by Ass. Prof. David Blair).

RECOMMENDATION 2

That satellite tagging programs be continued and expanded along the WA coastline to determine important habitat areas and movement between them.

This report has shown that it is difficult to quantify movement between habitat areas using aerial survey data because the associated error of density estimates prevents us from detecting fine scale population changes. Satellite tagging programs provide direct evidence of long-range movement between habitat areas (Sheppard et al. 2006) and provide additional information about movement corridors and timing. The data are useful in addition to the genetic data, for defining the spatial scale at which dugongs should be managed. Satellite tags now provide fine scale movement data from which it is possible to obtain detailed habitat use patterns (e.g. Sheppard et al. 2006). This would allow managers to identify important dugong habitat areas along the WA coastline through modelling techniques as per Recommendation 4.

RECOMMENDATION 3

That the program of aerial surveys in Shark Bay, Ningaloo Reef and Exmouth Gulf be continued, but extended to include dugong habitat northward of the Ningaloo-Exmouth region, to provide the basis for a spatial risk assessment of dugongs in WA.

Following Recommendations 1 and 2, the current aerial survey monitoring program of Shark Bay should be redesigned at a spatial scale consistent with the movements and relatedness between dugong populations along the WA coastline. In particular, a survey of the Kimberley coastline is urgently needed. This survey could be stratified, incorporating higher intensity sampling over areas suggested as high density dugong areas according to anecdotal data such as sightings from Coast Watch. This program would need to take into account logistical constraints of large scale aerial surveys. The logistical and funding requirements to implement an expansive monitoring program need to be investigated. Aerial survey methodology continues to be developed and new technologies such as unmanned aerial vehicles (UAVs) may alleviate these logistical and funding issues in the future. Knowledge of dugong distribution and abundance along the WA coastline would provide the basis for a spatial risk assessment to be conducted to determine the extent to which dugongs are at risk from human activities in WA. This is an important consideration in the Kimberley region in light of current expansion of the oil and gas industry as well as hunting pressures (see Recommendation 4).

RECOMMENDATION 4

That a spatially explicit dugong density model be developed for Shark Bay and the Exmouth/Ningaloo region from which, the conservation value of various habitats within the regions can be identified and spatial risk assessments can be conducted.

Grech and Marsh (2007) were able to prioritise areas of the Great Barrier Reef World Heritage Area for the conservation of dugongs through the development of a dugong density spatial model using data from a series of aerial surveys. They then went on to produce a spatial risk assessment for the most threatening human impacts for dugongs throughout this region. Similar models could readily be developed for Shark Bay and Exmouth/Ningaloo using the data already obtained from aerial surveys and would be an extremely valuable tool for determining high priority areas for the protection of dugongs, and assessing the impacts of proposed developments within or close to dugong habitat. These models could then be extended to areas further north once the aerial survey program has been extended.

RECOMMENDATION 5

That future dugong research in northern Western Australia incorporates the early involvement of stakeholder groups to facilitate knowledge exchange with traditional Indigenous owners, co-payment by industry, and risk assessment of future developments.

Any future dugong research in Western Australia should be modelled on Holley's (2006) study in Shark Bay which was heavily dependent on the involvement of the traditional Indigenous owners throughout the entire research process. Other stakeholder groups should also be consulted at the early stages of any research activity, particularly in the Pilbara and Kimberley regions. Collaborations with industry groups such as aquaculture and oil and gas would aid in determining research needs and encourage industry to co-invest in dugong research given their interest in the outcomes of studies that will determine key dugong habitats in northern Western Australia.

ACKNOWLEDGEMENTS

We thank the Department of Environment and Conservation (DEC) Shark Bay District, and DEC Exmouth District for providing the funding this project. We appreciate the efforts of all those who have contributed to the collection of these data since 1989. The data analysis was conducted with considerable input from Simon Blomberg, Steven Delean and Josh Smith.

REFERENCES

Blair, D., B. McDonald, A. McMahon, D. Tikel, M. Waycott and H. Marsh (in review). "Phylogeography and population genetic structure of the dugong in Australian waters: implications for conservation." Molecular Ecology.

CALM (1996). "Shark Bay Marine Reserves Management Plan 1996-2006, Management Plan No 34." pp. 114. Department of Conservation and Land Management for the National Parks and Nature Conservation Authority, Perth, Western Australia.

CALM and MPRA (2005). "Management Plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area 2005 - 2015, Management Plan No 52." pp. 112. Department of Conservation and Land Management and Marine Parks Reserves Authority, Perth, Western Australia.

Gales, N. J., R. D. McCauley, J. M. Lanyon and D. K. Holley (2004). "Change in abundance of dugongs in Shark Bay, Ningaloo and Exmouth Gulf, Western Australia: evidence for large scale migration." Wildlife Research **31**: 283-290.

Grech, A. and H. Marsh (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. and H. Marsh (2008). "Rapid assessment of risks to a mobile marine mammal in an ecosystem-scale marine protected area." Conservation Biology **22**(3): 711-720.

Hodgson, A. J. (2007). "The distribution, abundance and conservation of dugongs and other marine megafauna in Shark Bay Marine Park, Ningaloo Reef Marine Park and Exmouth Gulf." pp. 47. WA Department of Environment and Conservation, Denham, Western Australia.

Holley, D. K. (2006), Movement patterns and habitat usage of Shark Bay dugongs. Masters thesis, School of Natural Sciences. Edith Cowan University. Perth, Western Australia.

Holley, D. K., I. R. Lawler and N. J. Gales (2006). "Summer survey of dugong distribution and abundance in Shark Bay reveals additional key habitat area." Wildlife Research **33**(3): 243-250.

IUCN (2007). "2007 IUCN Red List of Threatened Species." <www.iucnredlist.org>, Downloaded on 12 May 2008.

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

Marsh, H. and D. F. Sinclair (1989). "An experimental evaluation of dugong and sea turtle aerial survey techniques." Australian Wildlife Research **16**: 639-650.

Marsh, H., R. I. T. Prince, W. K. Saalfeld and R. Shepherd (1994). "The distribution and abundance of the dugong in Shark Bay, Western Australia." Wildlife Research **21**: 149-161.

Norton-Griffiths, M. (1978). Counting Animals. Handbook No 1. Kenya, Serengeti Biological Monitoring Programme, African Wildlife Leadership Foundation.

Pollock, K., H. Marsh, I. R. Lawler and M. W. Aldredge (2006). "Estimating animal abundance in heterogeneous environments: an application to aerial surveys for dugongs." Journal of Wildlife Management **70**: 255-262.

Preen, A. R., H. Marsh, I. R. Lawler, R. I. T. Prince and R. Shepherd (1997). "Distribution and abundance of dugongs, turtles, dolphins and other megafauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia." Wildlife Research **24**: 185-208.

Prince, R. I. T. (2001). "Aerial survey of the distribution and abundance of dugongs and associated macrovertebrate fauna - Pilbara coastal and offshore region, WA." pp. 46. Environment Australia Marine Species Protection Program and Department of Conservation and Land Management WA, Perth, Western Australia.

Sheppard, J. K., A. R. Preen, H. Marsh, I. R. Lawler, S. D. Whiting and R. E. Jones (2006). "Movement heterogeneity of dugongs, *Dugong dugon* (Muller) over large spatial scales." Journal of Experimental Marine Biology and Ecology **334**(1): 64-83.

Taylor, B. L., M. Martinez, T. Gerrodette, J. Barlow and Y. N. Hrovat (2007). "Lessons from monitoring trends in abundance of marine mammals." Marine Mammal Science **23**(1): 157-175.

Walker, D. I. (1989). Seagrass in Shark Bay - the foundations of an ecosystem. Biology of Seagrass: A treatise on the biology of seagrasses with special reference to the Australian region. A. W. D. Larkum, A. J. McComb and S. A. Shepherd. Amsterdam, Elsevier**:** 182-210.

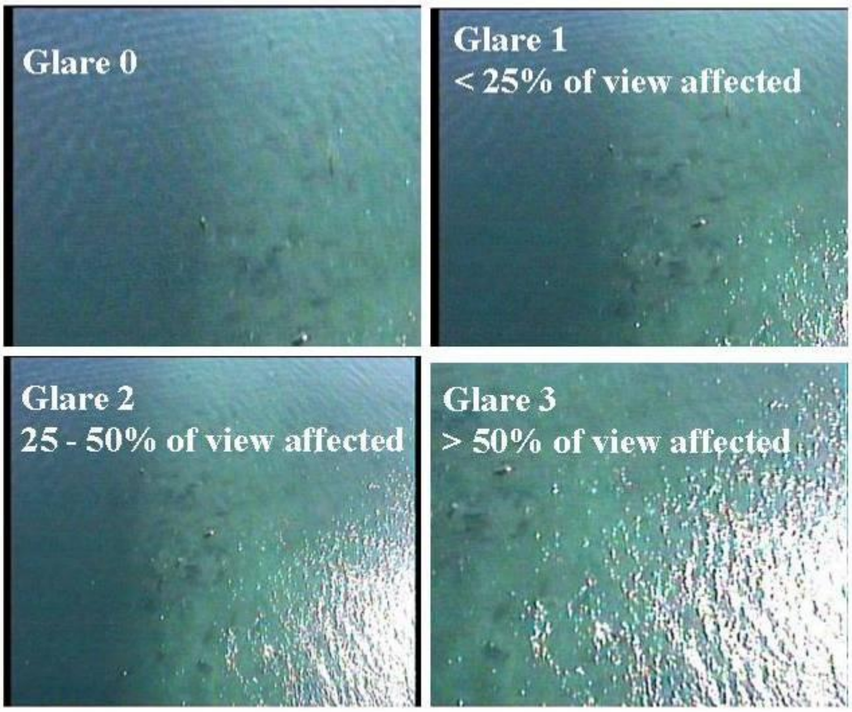
White, G. and K. P. Burnham (1999). "Program MARK: survival estimation from populations of marked animals." Bird Study **46**: 120-139.

APPENDIX 1: Scales for environmental conditions

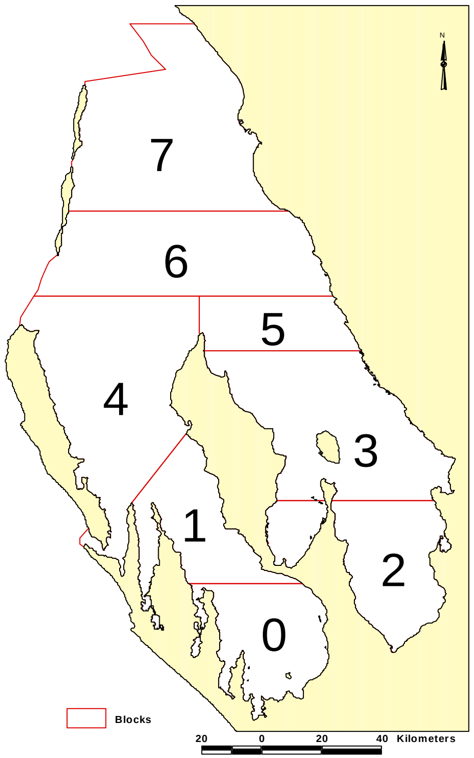
Turbidity Scale

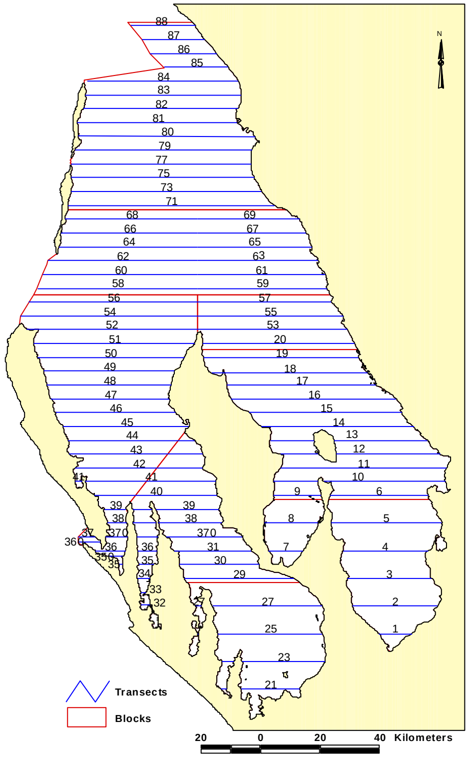
Turbidity	Water Quality	Depth Range	Visibility of Sea Floor
1	Clear	Shallow	Clearly visible
2	Variable	Variable	Visible but unclear
3	Clear	>5m	Not visible
4	Turbid	Variable	Not visible

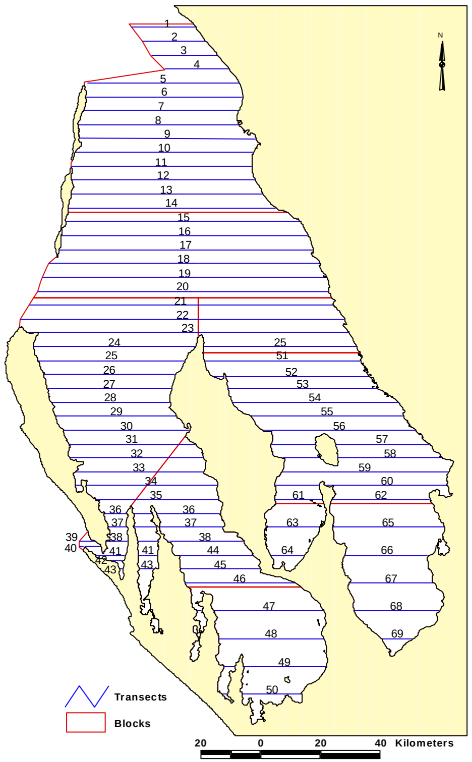
Glare Scale

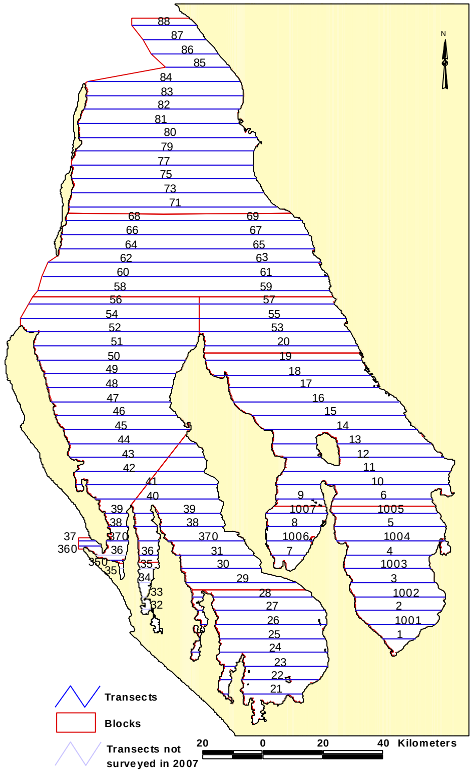


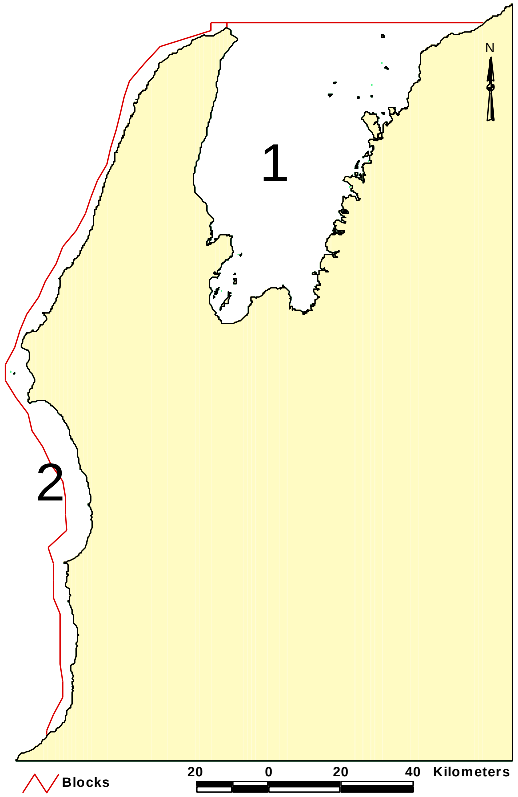
APPENDIX 2: Maps of blocks and transects surveyed each year

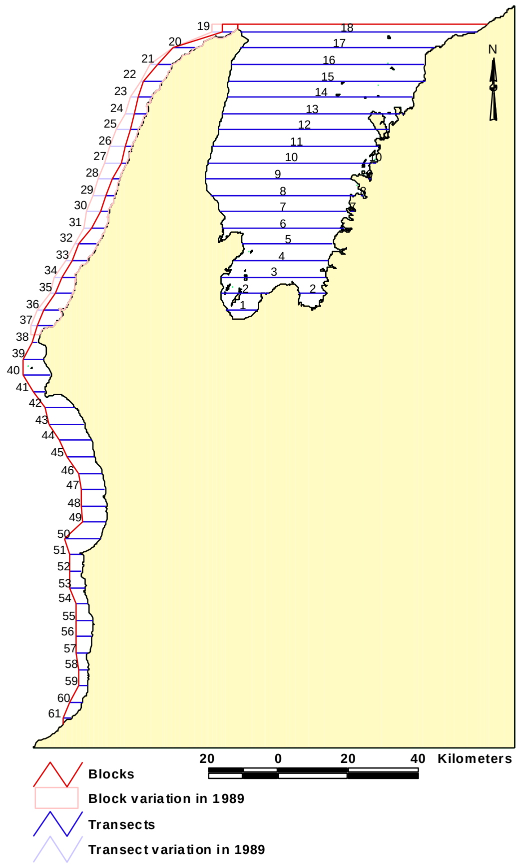


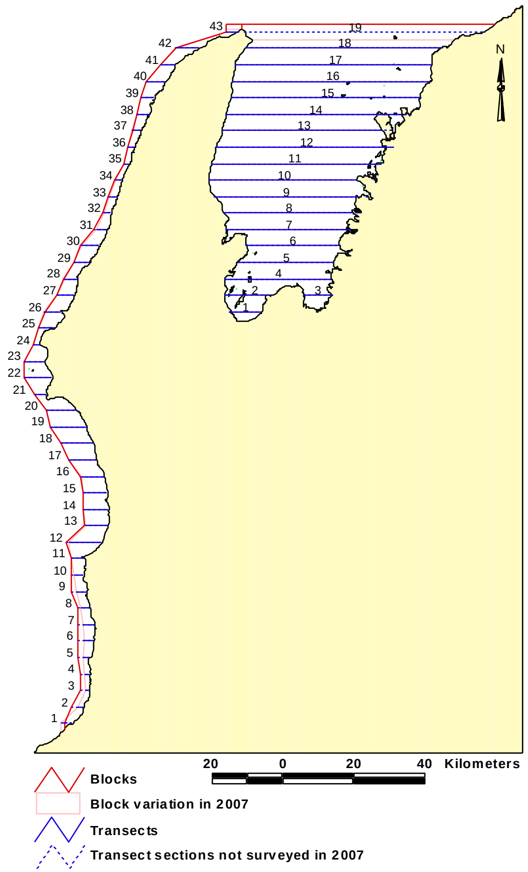







1
2
N
20 0 20 40 Kilometers
Blocks


N
20 0 20 40 Kilometers
Blocks
Block variation in 1989
Transects
Transect variation in 1989


N
20 0 20 40 Kilometers
Blocks
Block variation in 2007
Transects
Transect sections not surveyed in 2007

APPENDIX 3: Maps of sightings each year in Shark Bay, Exmouth Gulf and Ningaloo Reef

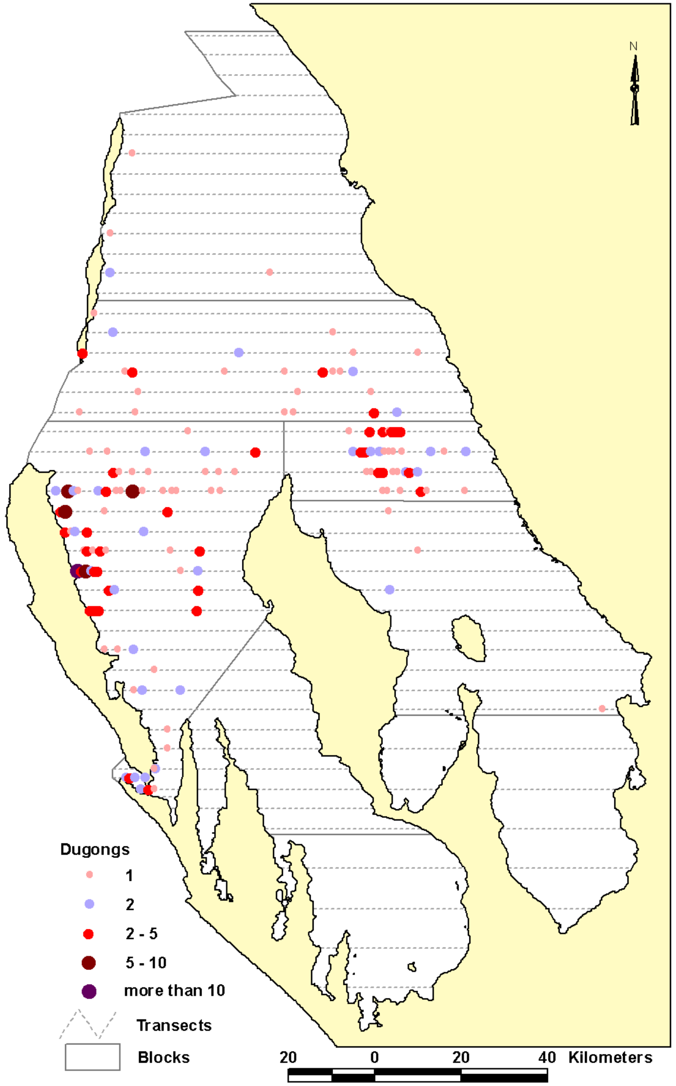


Figure A1. Shark Bay dugong sightings 1989.

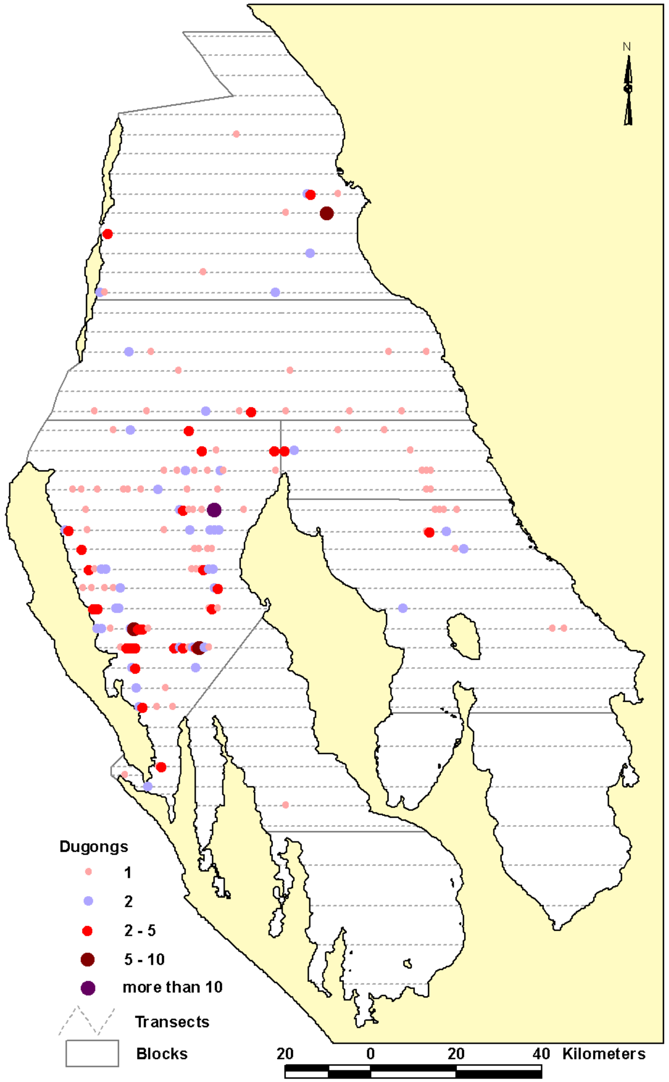


Figure A2. Shark Bay dugong sightings 1994.

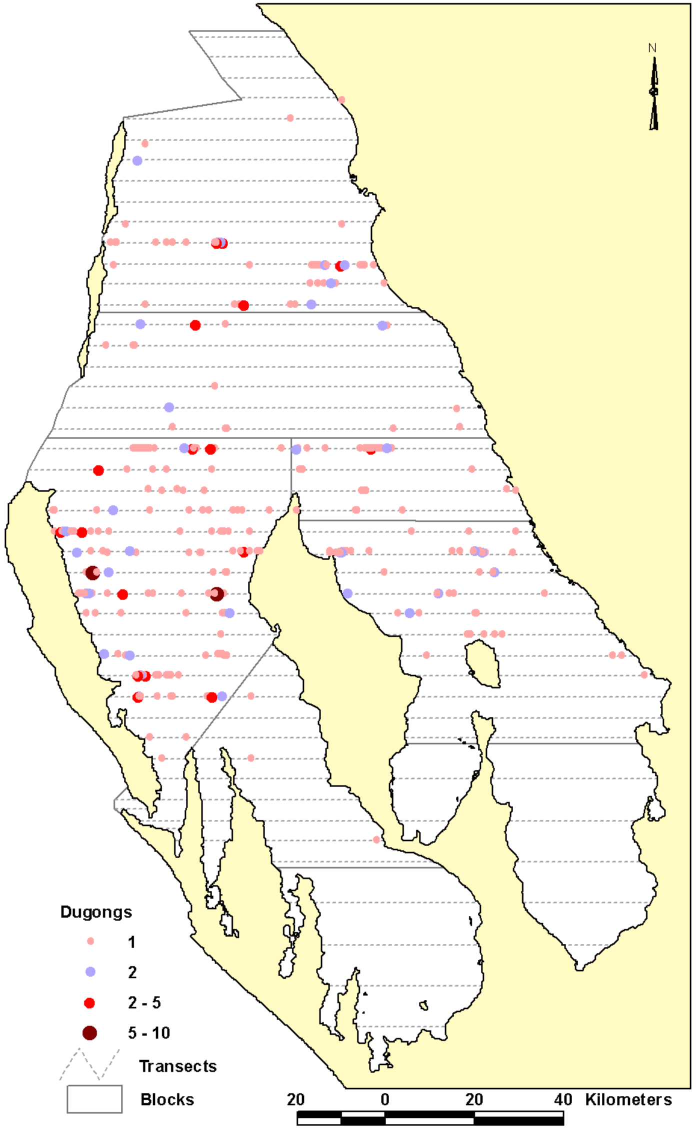


Figure A3. Shark Bay dugong sightings 1999.

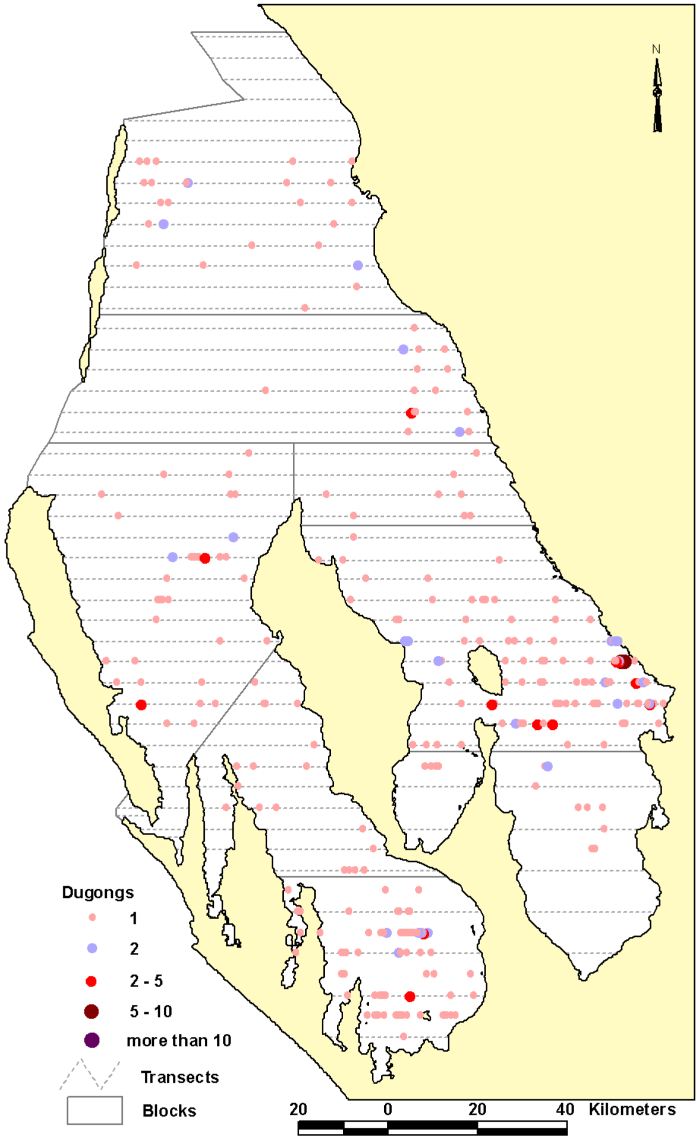


Figure A4. Shark Bay dugongs sightings 2002.

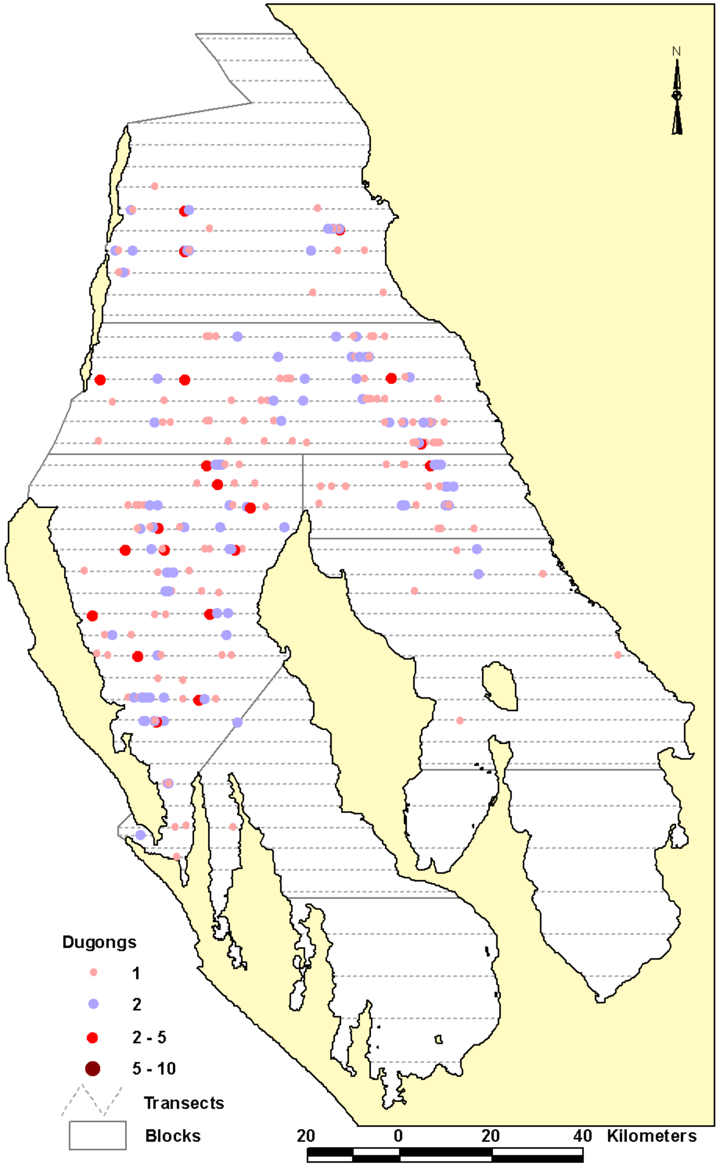


Figure A5. Shark Bay dugong sightings 2007.

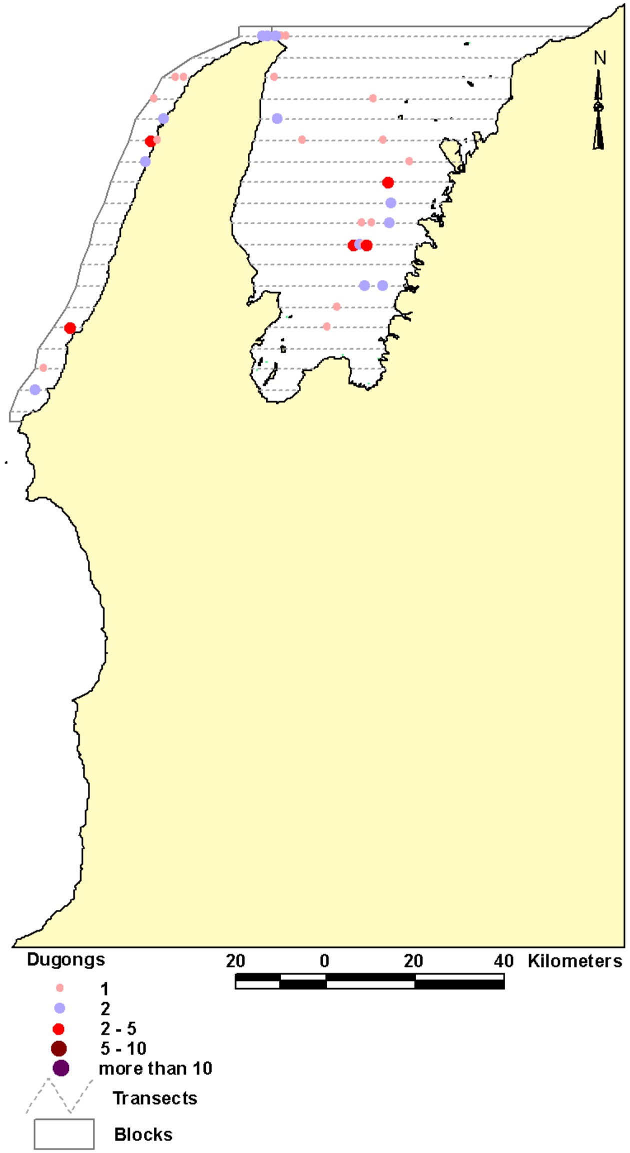


Figure A6. Exmouth Gulf and Ningaloo Reef dugong sightings 1989.

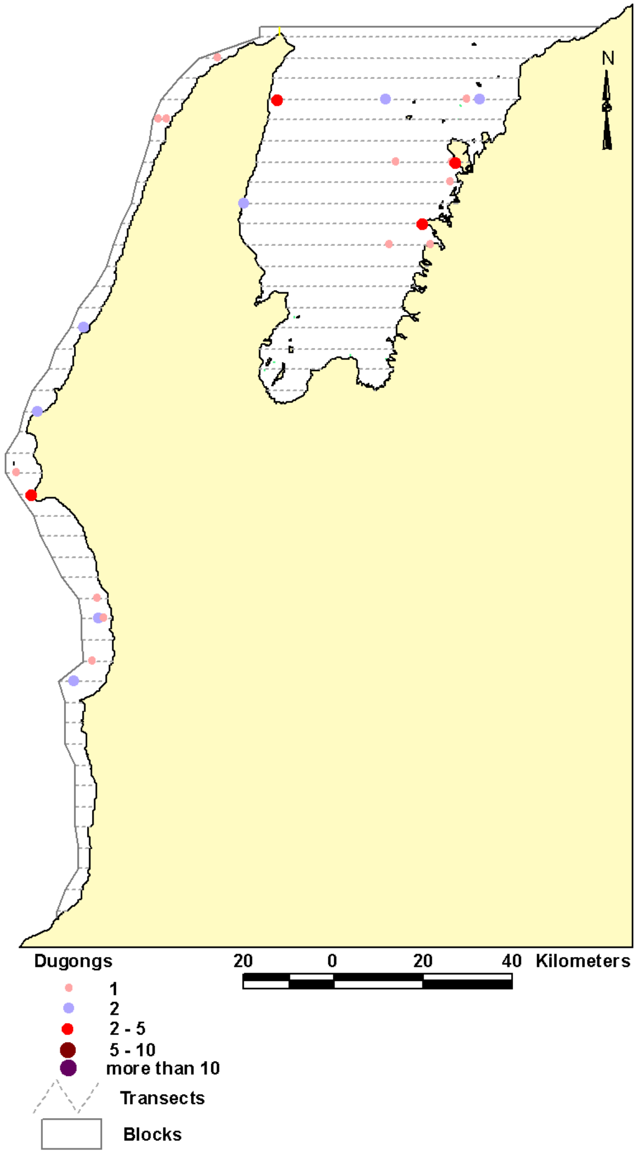


Figure A7. Exmouth Gulf and Ningaloo Reef dugong sightings 1994.

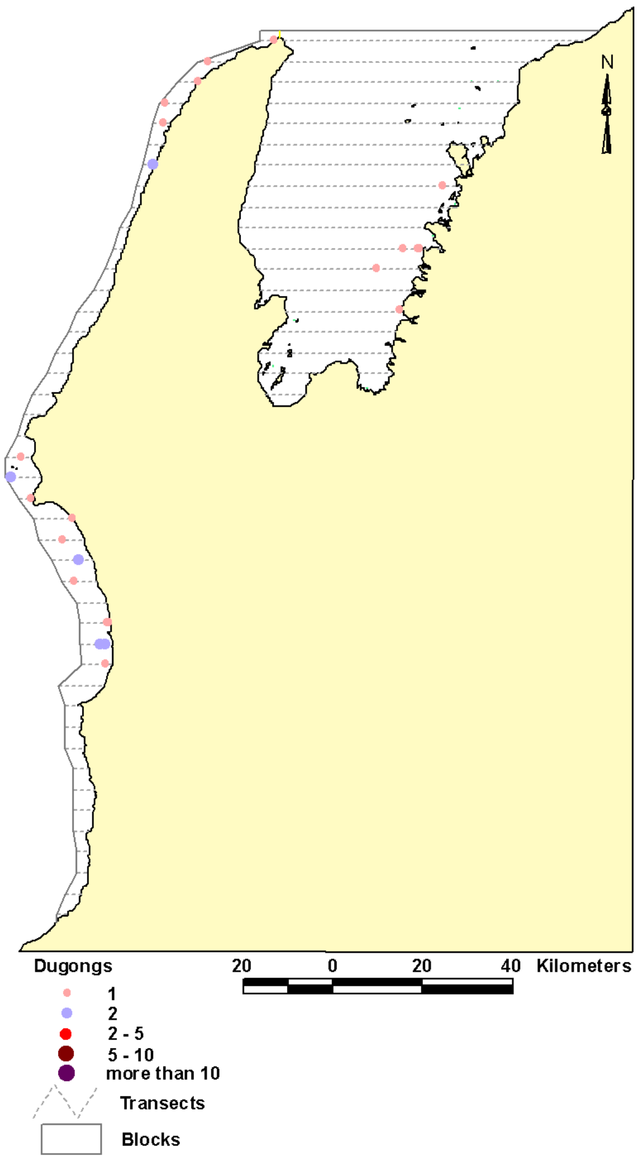


Figure A8. Exmouth Gulf and Ningaloo Reef dugong sightings 1999.

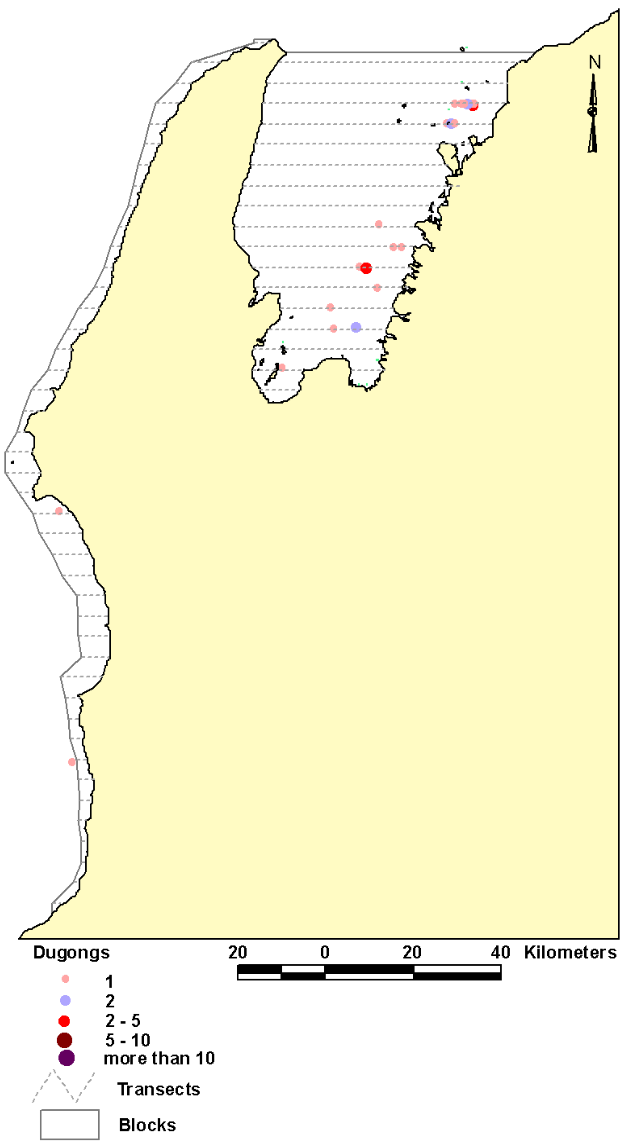


Figure A9. Exmouth Gulf and Ningaloo Reef dugong sightings 2007.

APPENDIX 4: Densities used in comparisons among years

Tran = transect number, Lgth = transect length, Ht Cor = Height correction factor used to calculate area surveyed, Dugs = Corrected number of dugongs, Dens = density of dugongs in the transect

	2007					2002					1999					1994					1989				
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
SB0	21	23.8	1.01		0.00	21	24.4	0.97	3	0.13	50	19.5	1		0.00	21	19.5	1.02		0.00	21	19.5	1.02		0.00
SB0	22	29.5	1.06		0.00	22	30.3	0.96	39	1.33	na					na					na				
SB0	23	30.8	1.04		0.00	23	31.7	0.95	30	0.98	49	28.4	1		0.00	23	28.4	1.01		0.00	23	28.4	1.04		0.00
SB0	24	40.7	1.02		0.00	24	41.8	0.94	18	0.46	na					na					na				
SB0	25	37.7	1.07		0.00	25	38.7	0.93	30	0.83	48	31.9	1		0.00	25	31.9	1.01		0.00	25	31.9	1.00		0.00
SB0	26	37.8	1.03		0.00	26	38.8	0.92	72	2.02	na					na					na				
SB0	27	38.2	1.02		0.00	27	39.3	0.90	24	0.67	47	34.8	1		0.00	27	34.8	1.00		0.00	27	34.8	1.05		0.00
SB0	28	36.1	1.05		0.00	28	37.0	0.89	9	0.28	na					na					na				
SB0	29	33.0	1.01		0.00	29	33.9	1.00	12	0.35	46	33.0	1		0.00	29	33.0	1.00		0.00	29	33.0	1.02		0.00
SB0	30	24.0	1.03		0.00	30	24.6	1.00	3	0.12	45	24.0	1	3	0.14	30	24.0	1.00	5	0.22	30	24.0	1.00		0.00
SB1	31	23.4	1.02		0.00	31	24.0	1.00	3	0.13	44	23.4	1		0.00	31	23.4	1.00		0.00	31	23.4	1.01		0.00
SB1	na					na					43	4.5	1		0.00	35	4.5	1.00		0.00	35	4.5	1.00		0.00
SB1	36	5.7	1.07		0.00	36	5.6	1.00		0.00	41	5.8	1		0.00	36	5.8	1.00		0.00	36	5.8	0.98		0.00
SB1	38	31.7	1.03		0.00	38	26.0	1.00	3	0.11	37	26.3	1		0.00	38	26.3	1.01		0.00	38	26.3	0.99		0.00
SB1	39	26.8	1.06		0.00	39	24.8	1.00	9	0.37	36	24.9	1	4	0.14	39	24.9	1.03		0.00	39	24.9	1.00		0.00
SB1	40	26.0	0.99		0.00	40	24.8	1.00	3	0.12	35	24.7	1	14	0.55	40	24.7	1.00		0.00	40	24.7	1.02		0.00
SB1	41	24.9	1.07		0.00	41	21.0	1.00		0.00	34	21.2	1	17	0.81	41	21.2	0.99		0.00	41	21.2	0.97		0.00
SB1	42	21.3	1.00		0.00	42	13.9	1.00	9	0.65	33	13.9	1	4	0.25	42	13.9	1.02		0.00	42	13.9	1.00		0.00
SB1	43	14.2	1.04		0.00	43	10.7	1.00	3	0.27	32	10.6	1	3	0.32	43	10.6	1.02		0.00	43	10.6	1.01		0.00
SB1	44	10.7	1.00		0.00	44	5.2	1.00		0.00	31	5.0	1		0.00	44	5.0	1.00		0.00	44	5.0	1.00		0.00
SB1	370	5.1	1.04		0.00	370	29.4	1.00	9	0.30	38	29.4	1	7	0.24	370	29.4	1.01		0.00	370	29.4	1.00		0.00
SB2	1	10.0	1.12		0.00	1	10.3	0.97		0.00	69	10.0	1		0.00	1	10.0	1.00		0.00	1	10.0	0.99		0.00

			2007					2002					1999					1994					1989		
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
SB2	2	25.7	1.11		0.00	2	26.3	0.95		0.00	68	25.7	1		0.00	2	25.7	1.02		0.00	2	25.7	1.01		0.00
SB2	3	25.4	1.10		0.00	3	26.1	0.93		0.00	67	25.4	1		0.00	3	25.4	1.01		0.00	3	25.4	1.01		0.00
SB2	4	25.8	1.03		0.00	4	26.4	0.91	3	0.13	66	25.8	1		0.00	4	25.8	1.00		0.00	4	25.8	1.00		0.00
SB2	5	33.5	1.07		0.00	5	34.4	1.05	3	0.09	65	33.5	1		0.00	5	33.5	1.00		0.00	5	33.5	1.01		0.00
SB2	7	10.4	1.00		0.00	7	10.7	1.00		0.00	64	10.4	1		0.00	7	10.4	1.01		0.00	7	10.4	1.01		0.00
SB2	8	16.1	1.00		0.00	8	16.5	1.00		0.00	63	16.1	1		0.00	8	16.1	1.02		0.00	8	16.1	0.99		0.00
SB2	1001	20.1	0.99		0.00	1001	20.7	0.96		0.00	na					na					na				
SB2	1002	27.4	1.06		0.00	1002	28.1	0.94		0.00	na					na					na				
SB2	1003	26.0	1.03		0.00	1003	26.6	0.92	6	0.24	na					na					na				
SB2	1004	32.7	1.03		0.00	1004	33.5	1.04	9	0.26	na					na					na				
SB2	1005	31.7	1.07		0.00	1005	32.5	1.07	6	0.17	na					na					na				
SB2	1006	13.8	1.06		0.00	1006	14.2	1.03		0.00	na					na					na				
SB2	1007	18.4	1.08		0.00	1007	18.9	1.06	12	0.59	na					na					na				
SB3	6	29.6	1.03		0.00	6	30.3	1.08	6	0.18	62	29.6	1		0.00	6	29.6	1.00		0.00	6	29.6	1.00	4	0.14
SB3	9	14.5	0.96		0.00	9	14.8	1.08	12	0.75	61	14.5	1		0.00	9	14.5	1.01		0.00	9	14.5	1.00		0.00
SB3	10	52.0	1.04		0.00	10	49.4	1.01	36	0.73	60	49.9	1	4	0.07	10	49.9	1.01		0.00	10	49.9	1.03		0.00
SB3	11	50.1	1.05	5	0.09	11	51.4	1.01	72	1.38	59	50.1	1	4	0.07	11	50.1	1.00		0.00	11	50.1	1.01		0.00
SB3	12	48.2	1.01		0.00	12	42.7	1.02	60	1.39	58	42.8	1	3	0.08	12	42.8	1.00		0.00	12	42.8	1.05		0.00
SB3	13	47.6	1.01		0.00	13	42.6	1.02	69	1.57	57	41.6	1	14	0.34	13	41.6	1.00	10	0.25	13	41.6	1.02		0.00
SB3	14	46.2	1.03	5	0.10	14	47.3	1.03	42	0.87	56	46.2	1	35	0.75	14	46.2	1.01	5	0.11	14	46.2	1.05		0.00
SB3	15	46.1	1.00		0.00	15	47.2	1.00	21	0.44	55	46.1	1	17	0.37	15	46.1	1.01		0.00	15	46.1	1.01	4	0.09
SB3	16	49.9	1.03		0.00	16	51.1	1.00	21	0.41	54	49.9	1	21	0.42	16	49.9	0.96		0.00	16	49.9	1.05		0.00
SB3	17	45.2	1.02	5	0.11	17	46.3	0.98	6	0.14	53	45.2	1	17	0.38	17	45.2	1.01	10	0.22	17	45.2	1.01	4	0.09
SB3	18	47.3	1.08	10	0.19	18	48.5	1.04	9	0.18	52	47.3	1	42	0.88	18	47.3	1.00	21	0.44	18	47.3	1.02		0.00
SB3	19	47.2	1.06	10	0.19	19	48.3	1.03	3	0.06	51	47.2	1	14	0.30	19	47.2	1.02	21	0.44	19	47.2	1.02	4	0.09
SB4	na					na					43	1.0	1		0.00	35	1.0	1.00		0.00	35	1.0	1.00		0.00

	2007					2002					1999					1994					1989				
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
SB4	na					36	9.0	1.00		0.00	41	9.0	1		0.00	36	9.0	1.02	5	0.55	36	9.0	1.02	20	2.21
SB4	37	5.1	0.87		0.00	37	5.2	1.00		0.00	39	5.1	1	3	0.66	37	5.1	1.00		0.00	37	5.1	1.00		0.00
SB4	38	6.3	1.00		0.00	38	5.9	1.00		0.00	37	6.0	1	3	0.56	38	6.0	1.04		0.00	38	6.0	1.00	4	0.67
SB4	39	6.9	1.00	15	2.14	39	6.7	1.00		0.00	36	6.6	1	3	0.51	39	6.6	1.03		0.00	39	6.6	1.01	4	0.61
SB4	40	12.1	0.99		0.00	40	12.3	1.00		0.00	35	12.3	1	7	0.56	40	12.3	1.01	21	1.66	40	12.3	1.00		0.00
SB4	41	21.4	1.13		0.00	41	20.4	1.00	6	0.29	34	20.3	1	55	2.73	41	20.3	1.01	15	0.75	41	20.3	1.01	15	0.74
SB4	42	24.6	0.98	44	1.82	42	24.6	1.00	9	0.37	33	24.8	1	51	2.06	42	24.8	1.01	26	1.03	42	24.8	0.97	5	0.21
SB4	43	29.5	1.00	64	2.17	43	29.4	1.00	9	0.30	32	29.6	1	138	4.65	43	29.6	1.00	124	4.17	43	29.6	1.01	20	0.68
SB4	44	33.1	1.02	10	0.29	44	33.0	1.00	6	0.18	31	33.2	1	90	2.73	44	33.2	1.01	52	1.55	44	33.2	0.99		0.00
SB4	45	38.0	1.02	34	0.89	45	38.9	1.00	6	0.16	30	38.0	1	34	0.91	45	38.0	1.01	52	1.34	45	38.0	1.06	37	0.91
SB4	46	36.4	1.02	20	0.53	46	37.3	1.00	3	0.08	29	36.4	1	28	0.77	46	36.4	1.01	47	1.27	46	36.4	1.07	20	0.53
SB4	47	35.7	1.06	29	0.77	47	36.6	1.00	12	0.32	28	35.7	1	62	1.75	47	35.7	1.02	82	2.25	47	35.7	1.03	74	2.01
SB4	48	37.6	1.04	24	0.62	48	38.5	1.00	6	0.16	27	37.6	1	83	2.20	48	37.6	0.99	36	0.97	48	37.6	1.05	37	0.94
SB4	49	39.7	1.04	29	0.71	49	40.6	1.00	27	0.67	26	39.7	1	83	2.08	49	39.7	1.02	52	1.27	49	39.7	1.01	29	0.72
SB4	50	44.6	1.04	54	1.16	50	45.6	1.00	3	0.07	25	44.6	1	45	1.00	50	44.6	1.01	88	1.96	50	44.6	1.04	37	0.80
SB4	51	49.0	1.09	49	0.92	51	50.2	1.01	3	0.06	24	49.0	1	35	0.71	51	49.0	1.01	47	0.94	51	49.0	0.99	57	1.17
SB4	52	52.0	1.08	59	1.06	52	53.2	1.01	9	0.17	23	52.0	1	52	1.00	52	52.0	1.01	52	0.99	52	52.0	1.03	8	0.15
SB4	54	53.7	1.05	25	0.44	54	55.0	0.96	6	0.11	22	53.7	1	58	1.08	54	53.7	1.00	26	0.48	54	53.7	1.03	24	0.44
SB4	56	51.2	1.05	30	0.55	56	52.4	0.95	3	0.06	21	51.2	1	17	0.34	56	51.2	1.00	16	0.31	56	51.2	1.01	4	0.08
SB4	350	4.0	0.89	5	1.35	na					42	4.0	1		0.00	350	4.0	1.00		0.00	350	4.0	1.07		0.00
SB4	360	6.7	0.83	5	0.90	360	6.8	1.00		0.00	40	6.7	1	3	0.50	360	6.7	1.02	5	0.74	360	6.7	0.98	29	4.41
SB4	370	6.8	0.92	10	1.56	370	6.4	1.00		0.00	38	6.7	1		0.00	370	6.7	1.00	10	1.55	370	6.7	1.00	12	1.85
SB5	20	46.2	1.03	20	0.41	20	47.3	1.02	9	0.18	24	46.2	1		0.00	20	46.2	1.00	10	0.22	20	46.2	1.02	33	0.70
SB5	53	45.6	1.05	39	0.82	53	46.6	1.02	9	0.19	23	45.6	1		0.00	53	45.6	0.99	16	0.35	53	45.6	1.02	37	0.79
SB5	55	44.2	1.04	49	1.06	55	45.2	0.97	3	0.07	22	44.2	1	28	0.63	55	44.2	0.99	20	0.46	55	44.2	1.01	57	1.29
SB5	57	40.8	1.07	39	0.91	57	41.7	0.94	3	0.08	21	40.8	1		0.00	57	40.8	1.00	10	0.25	57	40.8	1.04	58	1.35

	2007					2002					1999					1994					1989				
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
SB6	58	48.7	1.01	25	0.50	58	49.8	1.00	0	0.00	20.1	48.7	1	11	0.22	58	48.7	0.99	31	0.65	58	48.7	1.03	8	0.16
SB6	59	39.3	1.03	39	0.96	59	40.1	0.93	9	0.24	20.2	39.3	1	3	0.09	59	39.3	0.99	16	0.41	59	39.3	1.00	25	0.63
SB6	60	47.1	1.08	39	0.77	60	48.1	1.00		0.00	19.1	47.1	1	3	0.07	60	47.1	0.99		0.00	60	47.1	1.04	4	0.08
SB6	61	38.9	1.06	59	1.43	61	39.8	1.00	18	0.45	19.2	38.9	1	3	0.09	61	38.9	1.01		0.00	61	38.9	1.04	8	0.21
SB6	62	45.4	1.04	34	0.73	62	46.4	1.00	3	0.06	18.1	45.4	1	4	0.08	62	45.4	1.01	5	0.12	62	45.4	1.03	16	0.35
SB6	63	36.8	0.99	49	1.34	63	37.6	1.00	6	0.16	18.2	36.8	1	4	0.10	63	36.8	1.03	5	0.14	63	36.8	1.03	33	0.86
SB6	64	42.2	1.00	44	1.04	64	43.2	1.00		0.00	17.1	42.2	1		0.00	64	42.2	1.00	10	0.25	64	42.2	1.02	8	0.19
SB6	65	34.7	1.08	25	0.66	65	35.4	1.00	6	0.17	17.2	34.7	1		0.00	65	34.7	1.00	11	0.30	65	34.7	1.00	8	0.23
SB6	66	41.6	1.05		0.00	66	42.6	1.02		0.00	16.1	41.6	1	4	0.08	66	41.6	1.00		0.00	66	41.6	1.00	4	0.10
SB6	67	33.1	1.04	35	1.00	67	33.8	1.00	9	0.27	16.2	33.1	1		0.00	67	33.1	1.03		0.00	67	33.1	1.02	4	0.12
SB6	68	40.2	1.05	20	0.47	68	41.1	1.02		0.00	15.1	40.2	1	3	0.08	68	40.2	1.00		0.00	68	40.2	1.01	4	0.10
SB6	69	31.1	1.01	29	0.93	69	31.8	1.00	3	0.09	15.2	31.1	1	4	0.11	69	31.1	1.01		0.00	69	31.1	1.04		0.00
SB7	71	62.9	0.98		0.00	71	64.2	1.01	3	0.05	14	62.9	1	14	0.22	71	62.9	1.00	16	0.25	71	62.9	1.00		0.00
SB7	73	58.1	1.03	10	0.17	73	59.4	1.03	3	0.05	13	58.1	1	10	0.18	73	58.1	1.01	5	0.09	73	58.1	0.98	8	0.14
SB7	75	55.8	1.02	29	0.51	75	57.0	1.00	12	0.21	12	55.8	1	35	0.63	75	55.8	1.01	5	0.09	75	55.8	1.01		0.00
SB7	77	55.0	1.01	74	1.33	77	56.2	1.00	6	0.11	11	55.0	1	7	0.13	77	55.0	1.00	10	0.18	77	55.0	1.01	4	0.07
SB7	79	54.0	1.01	49	0.90	79	55.2	1.00	12	0.22	10	54.0	1	11	0.20	79	54.0	1.00	16	0.30	79	54.0	1.00		0.00
SB7	80	53.8	1.04	25	0.44	80	54.9	1.00	15	0.27	9	53.8	1	3	0.06	80	53.8	1.00	16	0.29	80	53.8	1.00		0.00
SB7	81	48.8	1.01	5	0.10	81	49.8	1.01	21	0.42	8	48.8	1		0.00	81	48.8	1.00		0.00	81	48.8	1.00		0.00
SB7	82	47.2	1.07		0.00	82	48.2	1.01	15	0.31	7	47.2	1	3	0.07	82	47.2	1.00		0.00	82	47.2	1.02	4	0.08
SB7	83	47.6	1.03		0.00	83	48.6	1.03		0.00	6	47.6	1		0.00	83	47.6	1.02	5	0.11	83	47.6	1.01		0.00
SB7	84	46.2	1.07		0.00	84	47.2	1.02		0.00	5	46.2	1		0.00	84	46.2	1.00		0.00	84	46.2	1.00		0.00
SB7	85	19.5	0.96		0.00	85	19.9	1.03		0.00	4	19.5	1		0.00	85	19.5	1.02		0.00	85	19.5	0.98		0.00
SB7	86	20.2	1.07		0.00	86	20.6	1.03		0.00	3	20.2	1		0.00	86	20.2	0.99		0.00	86	20.2	1.01		0.00
SB7	87	19.2	0.97		0.00	87	19.6	1.02		0.00	2	19.2	1		0.00	87	19.2	1.04		0.00	87	19.2	1.02		0.00
SB7	88	19.6	1.13		0.00	88	20.0	1.02		0.00	1	19.6	1		0.00	88	19.6	0.94		0.00	88	19.6	1.01		0.00

	2007					2002					1999					1994					1989				
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
EG1	1	8.4	1.02		0.00						1	8.4	1		0.00	1	8.5	1.00		0.00	1	8.5	1.00		0.00
EG1	2and3	17.9	1.07	6	0.29						2and3	17.9	1		0.00	2	20.0	0.99		0.00	2	20.0	1.00		0.00
EG1	4	27.7	1.03		0.00						4	27.7	1		0.00	3	27.7	0.99		0.00	3	27.7	1.00		0.00
EG1	5	25.1	1.11	11	0.40						5	25.1	1		0.00	4	24.9	1.00		0.00	4	24.9	1.00	3	0.14
EG1	6	23.9	1.02	5	0.19						6	23.9	1	1	0.06	5	24.0	1.00		0.00	5	24.0	1.00	4	0.15
EG1	7	32.4	1.08	6	0.16						7	32.4	1		0.00	6	32.3	1.01		0.00	6	32.3	1.00	10	0.32
EG1	8	33.6	1.00	14	0.42						8	33.6	1	1	0.04	7	34.4	1.00		0.00	7	34.4	1.02		0.00
EG1	9	36.8	1.07	9	0.24						9	36.8	1	4	0.11	8	38.8	1.00	13	0.34	8	38.8	1.00	24	0.63
EG1	10	38.4	0.99	5	0.12						10	38.4	1		0.00	9	38.9	1.00	13	0.33	9	38.9	1.03	11	0.26
EG1	11	42.9	1.07		0.00						11	42.9	1		0.00	10	44.1	0.98		0.00	10	44.1	1.02	3	0.08
EG1	12	46.3	0.97		0.00						12	46.3	1	1	0.03	11	44.0	1.00	6	0.14	11	44.0	1.01	7	0.16
EG1	13	41.7	1.02		0.00						13	41.7	1	1	0.03	12	45.1	1.01	20	0.43	12	45.1	1.01	4	0.08
EG1	14	45.9	1.03		0.00						14	45.9	1	3	0.05	13	47.4	1.03		0.00	13	47.4	1.01	7	0.15
EG1	15	49.4	1.04	15	0.29						15	49.4	1	3	0.05	14	49.3	1.00		0.00	14	49.3	1.01	4	0.07
EG1	16	51.5	1.05	56	1.04						16	51.5	1		0.00	15	52.0	1.00	39	0.75	15	52.0	1.00	3	0.07
EG1	17	51.0	0.99		0.00						17	51.0	1	1	0.03	16	51.2	1.01		0.00	16	51.2	1.00	4	0.07
EG1	18	51.0	1.04		0.00						18	51.0	1	1	0.03	17	51.4	1.01		0.00	17	51.4	1.01		0.00
EG1	na										19	62.6	1	1	0.02	18	62.8	1.00		0.00	18	62.8	1.00	11	0.17
NR1	43	3.3	1.01		0.00						43	3.3	1	1	0.37	19	3.2	1.09		0.00	19	5.9	1.00	3	0.54
NR1	42	6.2	1.00		0.00						42	6.2	1	1	0.19	20	5.8	1.00	6	0.98	20	5.9	1.00		0.00
NR1	41	3.6	1.04		0.00						41	3.6	1	1	0.32	21	3.7	0.98		0.00	21	5.9	1.01	3	0.54
NR1	40	5.2	1.14		0.00						40	5.2	1	1	0.24	22	5.1	1.00		0.00	22	5.9	1.00	2	0.27
NR1	39	3.7	1.03		0.00						39	3.7	1	1	0.31	23	3.8	1.02	12	3.00	23	5.9	1.00	2	0.27
NR1	38	3.3	1.04		0.00						38	3.3	1		0.00	24	3.3	1.00		0.00	24	5.9	1.00	6	1.08
NR1	37	2.2	1.09		0.00						37	2.2	1	1	0.52	25	2.2	0.99		0.00	25	5.9	0.99	2	0.28
NR1	36	1.7	1.06		0.00						36	1.7	1		0.00	26	1.9	0.98		0.00	26	5.9	1.00		0.00

Block	2007					2002					1999					1994					1989				
	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
NR1	35	1.5	0.99		0.00						35	1.5	1		0.00	27	1.7	1.01		0.00	27	5.9	0.99		0.00
NR1	34	1.6	1.07		0.00						34	1.6	1		0.00	28	1.9	1.04		0.00	28	5.9	1.00		0.00
NR1	33	2.0	0.89		0.00						33	2.0	1		0.00	29	2.2	0.99		0.00	29	5.8	0.99		0.00
NR1	32	1.7	1.07		0.00						32	1.7	1		0.00	30	2.2	1.02		0.00	30	5.8	1.03		0.00
NR1	31	2.9	1.12		0.00						31	2.9	1		0.00	31	3.7	1.00		0.00	31	5.8	1.00		0.00
NR1	30	4.5	1.09		0.00						30	4.5	1		0.00	32	4.8	1.01		0.00	32	5.8	1.06		0.00
NR1	29	4.1	0.98		0.00						29	4.1	1		0.00	33	4.0	1.01	6	1.40	33	5.8	1.01	2	0.27
NR1	28	3.4	1.13		0.00						28	3.4	1		0.00	34	3.8	1.00		0.00	34	5.8	0.99		0.00
NR1	27	4.5	1.00		0.00						27	4.5	1		0.00	35	4.5	1.01		0.00	35	5.8	1.01	2	0.27
NR1	26	4.5	1.09		0.00						26	4.5	1		0.00	36	4.3	1.02		0.00	36	5.8	1.00	2	0.27
NR1	25	4.5	0.94		0.00						25	4.5	1		0.00	37	4.4	1.00	6	1.37	37	5.8	1.00		0.00
NR1	24	1.7	1.11		0.00						24	1.7	1		0.00	38	1.5	1.00		0.00	na				
NR1	23	5.5	1.06		0.00						23	5.5	1	1	0.21	39	5.6	1.02		0.00	na				
NR1	22	7.2	1.13		0.00						22	7.2	1	1	0.16	40	7.3	1.02	6	0.79	na				
NR1	21	3.0	0.87		0.00						21	3.0	1	1	0.41	41	3.2	1.02	12	3.62	na				
NR1	20	8.0	0.96		0.00						20	8.0	1	1	0.15	42	8.0	1.03		0.00	na				
NR1	19	9.3	1.01		0.00						19	9.3	1		0.00	43	9.2	1.01		0.00	na				
NR1	18	8.2	1.02		0.00						18	8.2	1		0.00	44	8.4	1.00		0.00	na				
NR1	17	7.0	1.07		0.00						17	7.0	1		0.00	45	7.2	1.02		0.00	na				
NR1	16	5.9	1.08		0.00						16	5.9	1		0.00	46	6.0	1.01	6	0.93	na				
NR1	15	6.2	0.99		0.00						15	6.2	1		0.00	47	6.3	1.04	12	1.77	na				
NR1	14	6.5	0.99		0.00						14	6.5	1		0.00	48	6.6	1.01		0.00	na				
NR1	13	5.9	0.97		0.00						13	5.9	1		0.00	49	6.2	1.02	6	0.90	na				
NR1	12	8.8	1.08		0.00						12	8.8	1		0.00	50	9.4	1.00	6	0.60	na				
NR1	11	3.1	1.11		0.00						11	3.1	1		0.00	51	3.3	1.00		0.00	na				
NR1	10	2.2	1.11		0.00						10	2.2	1		0.00	52	3.3	1.02		0.00	na				

	2007					2002					1999					1994					1989				
Block	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens	Tran	Lgth	Ht Cor	Dugs	Dens
NR1	9	2.8	1.16		0.00						9	2.8	1		0.00	53	4.1	1.00		0.00	na				
NR1	8	2.6	1.07		0.00						8	2.6	1		0.00	54	3.1	1.00		0.00	na				
NR1	7	3.2	1.13		0.00						7	3.2	1		0.00	55	4.4	1.02		0.00	na				
NR1	6	2.4	1.00		0.00						6	2.4	1		0.00	56	4.1	1.00		0.00	na				
NR1	5	1.5	1.07		0.00						5	1.5	1		0.00	57	3.3	0.98		0.00	na				
NR1	4	1.4	1.04		0.00						4	1.4	1		0.00	58	2.4	1.00		0.00	na				
NR1	3	0.9	0.93		0.00						3	0.9	1		0.00	59	2.1	0.98		0.00	na				
NR1	2	1.4	0.89		0.00						2	1.4	1		0.00	60	3.3	1.00		0.00	na				
NR1	1	1.7	1.07		0.00						1	1.7	1		0.00	61	2.1	1.00		0.00	na				