DISTRIBUTION AND ABUNDANCE OF DUGONGS AND OTHER MEGAFAUNA IN MORETON BAY AND HERVEY BAY BETWEEN DECEMBER 2000 AND NOVEMBER 2001

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EXECUTIVE SUMMARY

- In response to an outbreak of the potentially toxic algae *Lyngbya* over the eastern banks of Moreton Bay in March 2000, a series of aerial surveys was planned to asses the effects of future outbreaks on the distribution and abundance of dugongs and other megafauna in Moreton Bay. As the outbreaks appear to be seasonal it was anticipated that a similar outbreak would occur in late summer of 2000/2001. Thus, the planned aerial surveys were to be conducted in December 2000, February 2001 and May 2001 (before, during and after the expected outbreak).
- The pre-outbreak aerial survey was conducted in December 2000. Fortunately, the outbreak of *Lyngbya* did not eventuate and thus the series of surveys was not necessary for that purpose. However, the result of the survey was a population estimate for dugongs of 344 (±88 s.e.) which appeared to be a decline from 1995 estimates of up to 896 (±201) (although statistical comparison was not possible due to differences in methodology).
- In response to the perceived decline, the objectives of the study were altered by QPWS and neighbouring Hervey Bay was included in two subsequent surveys, one in April 2001 and the next in November 2001. This was because movement of dugongs from Moreton Bay to Hervey Bay was suggested, in the preliminary report, as the most reasonable (but not the only) explanation for the decline in Moreton Bay.
- The series of surveys showed no indication in terms of numbers or distribution to indicate that *Lyngbya* was affecting the distribution or abundance of dugongs. The April 2001 and November 2001 surveys of Moreton Bay returned dugong population estimates of 366 (±41) and 493 (±45) respectively. However, these results should not be taken to prove that there is no current effect, or potential for future effects, of *Lyngbya* on the Moreton Bay dugong population. Aerial survey provides coarse scale information and is not appropriate to detect subtle effects.
- Future research on this issue would more appropriately be directed at more detailed examination of dugong carcasses to determine causes of death of Moreton Bay dugongs, examination of stomach contents of dugong carcasses to determine whether *Lyngbya* is indeed ingested and perhaps pathological studies to determine whether dugongs absorb *Lyngbya* toxins and what effects this might have. This would give a more thorough understanding of the system and may enable the significance of events to be assessed in advance. Similarly, continued monitoring of *Lyngbya* occurrence and the ecological cues leading to outbreaks will be valuable.
- The results of the Moreton Bay surveys did not have sufficient statistical power to detect any trends in the population during the study, despite the November 2001 estimate being considerably higher. This is an inherent weakness of any monitoring scheme for wildlife populations over small scales. The estimates provided are within the range of previous estimates for Moreton Bay and are thus not, of themselves, particular cause for concern. The apparent decline in the dugong population of Moreton Bay since 1995 is impossible to assess because of the problem of low statistical power, confounded by different methodologies between the two studies.
- Population estimates for the dugong population of Hervey Bay also fluctuated (from 919 (±146) in April 2001 to 1708 (±392) in November 2001) but again these were not statistically significant. The dugong population of Hervey Bay appears to have recovered well since its catastrophic decline in response to large scale seagrass loss caused by severe flooding.
- There were no indications, within the course of this series of surveys, of substantial movements of individuals from Moreton Bay to Hervey Bay (or vice versa). However, the overall sequence of surveys since 1994 shows that there is potential for this to have occurred. Differences in methodologies and timing, and low statistical power, make such hypotheses difficult to assess formally.
- In light of the results of this study I suggest the following research as a minimum for the dugong population of Moreton Bay:
    - Monitoring of the seagrass resource available to dugongs.
    - Monitoring of the distribution and abundance of *Lyngbya*.
        - This should include further investigation into the toxins occurring in *Lyngbya*, the factors that cause them to vary, and their toxicity to dugongs and other significant fauna.

- Aerial surveys to continue but methodology and timing to be standardised and coordinated with future surveys of adjacent Hervey Bay and the Great Barrier Reef Marine Park (in collaboration with the agencies responsible for managing dugong populations in each of those areas).

CONTENTS

Introduction

Moreton Bay is an area renowned for its dugong population, the dugongs being consistently found in a restricted area in high densities and clear, shallow water. Since the "rediscovery" of its population by scientists in the late 1970s (Heinsohn et al. 1978) there have been ongoing attempts to monitor the population (Lear 1977, Marsh and Sinclair 1989b, Marsh et al. 1990, Preen 1993, Preen and Marsh 1995, Lanyon and Morrice 1997). Methodologies have differed substantially between surveys by different workers and thus attempts to determine the "normal" population size and trends are problematic. However, a feature of all surveys has been the recording of the great majority of dugongs over the Moreton and Amity Banks on the eastern side of the bay (Lear 1977, Heinsohn et al. 1978, Marsh and Sinclair 1989b, Marsh et al. 1990, Preen 1993, Lanyon and Morrice 1997). In the summer months more than 95% of dugongs are seen over this bank (Preen 1993, Lanyon and Morrice 1997). The distribution may alter in some winters as a result of reduced water temperatures over the shallow banks where the dugongs feed (Marsh and Sinclair 1989b, Preen 1993). However the banks remain the focal area for feeding activity (Preen 1993). During periods when water temperature is particularly low dugongs seek a thermal refuge in the deeper water of the Rous Channel and the oceanic waters offshore of the bay (Marsh and Sinclair 1989b, Preen 1993, Lanyon and Morrice 1997, Lawler and Marsh 2000). However, periodically they must move onto the banks in order to access the seagrass beds on which they rely.

The seagrass beds of the Amity and Moreton Banks are clearly now critical habitat for the Moreton Bay dugong population. Any process or activity that limits access to these beds or reduces their quality is thus likely to negatively impact the dugong population. Recent outbreaks of the toxic algae *Lyngbya majuscula* (hereafter referred to simply as *Lyngbya*) have raised fears that such an effect could occur.

Lyngbya is a filamentous cyanobacteria that contains multiple toxins known to cause contact determatitis and respiratory and eye irritation. In recent years there have been several outbreaks of *Lyngbya* in Moreton Bay (Osborne et al. 2001). A particularly severe outbreak occurred in March 2000 on the eastern banks of Moreton Bay. Managers of the bay (Queensland Parks and Wildlife Service, Cleveland Office) were concerned that further such outbreaks may harm the dugong population, either by smothering seagrass (Abal et al. 2001), and hence removing the food resource, or by growing over the seagrass and blocking access due to irritation likely to be caused as dugongs contacted the *Lyngbya* while trying to feed.

Currently the effects of *Lyngbya* on dugongs specifically are unknown. However, there is clear potential for dugongs to be impacted negatively by the occurrence of *Lyngbya* over the seagrass beds on which they depend. This study was initiated as part of efforts to assess the impact of such *Lyngbya* outbreaks on the dugong population of Moreton Bay. The original objective was to record the dugong distribution and abundance in Moreton Bay prior to an outbreak that was expected in the summer of 2000/2001 (based on the timing of the outbreak in March 2000) and then to assess how these changed during and after the outbreak. Thus a series of three aerial surveys of the Moreton Bay dugong population was planned for December 2000, February 2001 (during the expected outbreak) and after the expected outbreak.

Fortunately, the expected *Lyngbya* outbreak did not occur on the scale anticipated and it was thus not necessary to continue the survey schedule as originally planned. However, a notable finding of the first survey in the planned series was an *apparent* reduction in dugong numbers between the December 2000 survey and surveys conducted in 1995 (Lanyon and Morrice 1997). Despite significant differences in the methodology of the two studies, there was sufficient concern amongst managers to convince them that the survey series should be continued with different objectives and scheduling.

In April and November of 2001 the dugong population of Moreton Bay was surveyed again. However, one these occasions Hervey Bay, the nearest significant dugong habitat to Moreton Bay, was included in the survey. The rationale for this was that, if the dugong population of Moreton Bay had indeed declined it may have been the result of emigration of dugongs from Moreton Bay. The most likely destination for dugongs moving out of the area would be Hervey Bay. Thus any further decrease in the dugong population of Moreton Bay should be matched by a similar increase in the population in Hervey Bay. Prior to entering into the revised survey program I expressed concerns to QPWS staff that the statistical power of aerial surveys to detect such changes in small populations is very low and that, consequently, changes would have to be large to be detectable. I also noted that the timing of earlier surveys of Hervey Bay and Moreton Bay was such that any decrease may already have been recorded in earlier surveys. Both of these concerns are discussed in detail in the discussion section.

This document reports on the results of the series of three surveys, of Moreton Bay in December 2000 and of Moreton Bay and Hervey Bay combined in April and November of 2001. Data is provided also on turtles and cetaceans seen during the surveys, but as the methodology is less suited to these taxa (for reasons outlined below), they are given less emphasis.

Methodology

Survey design

Moreton Bay was surveyed on three occasions: between December 12th and 14th 2000 inclusive, April 18th and the morning of the 19th 2001 and November 28th to 30th 2001. Hervey Bay was surveyed on two occasions: between the afternoon of April 19th and the 20th 2001 and November 30th to December 2nd 2001.

Note that in December 2000, Moreton Bay Block 4 (where the majority of dugongs are seen) was surveyed twice, once on December 12th using only the two experienced observers in the team. It was surveyed again on December 13th using data from the tandem observer teams after they had been trained in the survey method.

The strip transect methodology developed by Marsh and Sinclair (1989a,b) was used, with the aircraft flown at 137m (450 feet) as in numerous previous surveys (Bayliss and Freeland 1989, Marsh and Saafeld 1989, 1990, Preen et al. 1995b, Marsh et al. 1997, Preen et al. 1997, Prince et al. 2001). Tandem teams of observers on each side of the aircraft recorded their sightings independently onto separate tracks of an audio tape. These independent sightings were then used to develop survey specific correction factors (see below).

Transect positions and lengths for Moreton Bay were based on those of the most recent surveys of the region (Lanyon and Morrice 1997)(Table 1, Figure 1a). Pummicestone Passage was also surveyed when the formal survey was complete. The survey design for Hervey Bay followed that of previous surveys (Preen and Marsh 1995, Marsh et al. 1996, Lawler and Marsh 2000)(Table 1, Figure 1b).

In Moreton Bay the majority of dugongs are found on the eastern banks (survey Block 4; Figure 1a) where they often form large herds. In order to ensure that no herds positioned between the transects were omitted from the data (which would lead to an underestimate of the population), after the formal survey of Block 4, the eastern banks were flown over again at greater altitude (365m/1200feet) to look for extra dugong herds. Herds were stratified out of the population estimate and added back in at the end of the analysis (Norton-Griffitsh 1978, Marsh and Sinclair 1989a). Data from herds also were not used in calculation of correction factors because it was not possible to determine the numbers at the surface.

The above approach was discussed in detail at a workshop of aerial survey experts at James Cook University in March 2002. Present at the meeting were Dr Anne Cowley (Statistical Consulting Unit, Australian National University – formerly of CSIRO Division of Marine Research, in charge of aerial surveys) , Professor Ken Pollock (Professor of Statistics, Biomathematics,and Zoology, North Carolina State University), Dr Glenn De’ath (Australian Institute of Marine Science) and Professor Helene Marsh (TESAG, James Cook University). All were satisfied that this was the optimal approach given the circumstances of dugong distribution in Moreton Bay.

Table 1. Areas of survey blocks and sampling intensities

Block	Area (km^2)	Sampling intensity (%)
Moreton Bay		
1	166	19.86
2	691	10.7
3	188	10.05
4	389	39.20
5	155	19.59
6	226	24.30
Hervey Bay		
1	517	19.6
2	1414	16.15
3	1235	8.69
4	1224	8.97
5	546	8.52

Observers

Two observers were used on each side of the aircraft. This enables the calculation of correction factors specific to each team to estimate the proportion of visible animals that are missed by that team (Marsh and Sincliar 1989a). In the first survey (of Moreton Bay only in December 2000) the two mid-seat observers had experience in multiple large-scale aerial surveys conducted using identical techniques. The two rear-seat observers were initially untrained but both are Marine Park rangers with experience in aerial surveillance. Training transects were flown over Block 4 to ensure that observers were familiar with the techniques used. In subsequent surveys (of Moreton and Hervey Bays) one of the rear seat observers trained in the first survey was used in the mid-seat and two more Marine Park rangers were used as rear seat observers. The team was the same for the April and November 2001 surveys.

Correction Factors

Two types of correction factors are estimated in order to develop the population estimate. These are the perception correction factor (PCF) which adjusts for the number of groups of animals that were available to be seen within the transect but were missed by each observer team. It is specific to the particular pair of observers on each side of the aircraft. The availability correction factor (ACF) adjusts for the proportion of animals that were in the transect zone, but below the surface of the water, such that they are unavailable for counting as the aircraft passes over.

For these surveys, the PCFs have been calculated across both bays within surveys, as the observers were consistent across the whole survey. However, ACFs have been treated differently, because Moreton Bay is a special case in terms of these types of aerial surveys. In most other areas, many of the dugongs are in deeper water where they are able to become unavailable for counting. In Moreton Bay, almost all dugongs are seen in shallow water over the banks in Block 4. Under these conditions, all animals are potentially available for counting and thus no availability correction factor is necessary. In terms of the methodology used here this is equivalent to using ACF=1. In contrast, in Hervey Bay, many of the animals are seen in deeper water and I have applied the ACF as per the methodology of Marsh and Sinclair (1989a) using only data from Hervey Bay. Similarly, the mean group size was calculated using data only from Hervey Bay, as inclusion of Moreton Bay data, where dugongs tend to group together more, would inflate the population estimate.

Note that on several occasions less than five dugongs were seen within a survey block. In these instances, I have noted the animals seen, but have not calculated a formal population estimate for that block due to the imprecision of such an estimate.

Statistical analysis

Differences in dugong density among survey years in Moreton Bay and Hervey Bay were examined using a split-plot form of analysis of variance. Mixed-effects models were employed to estimate the random components of variance for this analysis and to provide appropriate tests for differences between years. The parameters of these models were estimated by restricted maximum likelihood (REML). Variation in dugong density among blocks and among transects within blocks were random sources of variance, as was the variation due to the interaction among blocks across years. The (fixed) year effect was tested against the (random) block*year interaction using dugong density in each transect within blocks as the response. The data were log transformed (i.e. $\ln(y + 0.1)$) to ensure a constant mean-variance relationship. The test for the year effect assumed sphericity (i.e. constant correlation between blocks across years) and there was no evidence for violation of this assumption.

A combined analysis of changes over time in Moreton Bay and Hervey Bay was not attempted for several reasons:

(1) Both areas were not sampled in the same years;
(2) There was no among block variation in Moreton Bay in the 2001 surveys (i.e. all dugong were seen in Block 4 in surveys in that year);
(3) The majority of dugong seen in Moreton Bay were in herds (see below) whereas very few dugongs in Hervey Bay were in herds, and;
(4) There was no real evidence of changes in dugong density among years in either location and therefore there was no relationship among changes in both locations to examine.

A large proportion of dugongs observed in Moreton Bay were in herds. The number of individuals in these aggregations were estimated using a different sampling method than was used to estimate density on the transects. The proportion of dugong in herds was 36.7% in December 2000, 87.3% in April 2001, and 86% in November 2001. After correction factors were taken into account these proportions were 19%, 71% and 72%, respectively. These are extremely large proportions in the 2001 surveys. The estimation of differences in dugong density among years (which do not include counts of individuals in herds) will be affected by the level of aggregation in different years. To account for this fact the herd counts were incorporated into the estimates of density on given transects and these data analysed, ignoring the differences in the sampling methods used. This was deemed a biologically reasonable approach.

Turtles and cetaceans

Information is provided in this report on sightings of turtles and cetaceans. However, they are not a primary focus and aerial survey is not an ideal method for estimating the abundance of either group. Data on these taxa was collected incidental to the focus on dugongs. Consequently, there is limited discussion on these taxa in later sections. The effect of *Lyngbya* on cetaceans in particular is more indirect as they do not feed directly on seagrasses, the mode by which dugongs and green turtles are expected to encounter *Lyngbya*.

Population estimates for turtles have been calculated only for Moreton Bay. This is because estimates for turtles are problematic due to their unknown and variable diving behaviour, presence of small individuals unlikely to be seen and difficulty in making identifications to species. Moreton Bay estimates are provided to enable comparison to estimates made in 1995 but these should not be considered accurate estimates of population size (they are likely to be major underestimates). No estimates were calculated for Hervey Bay as no comparable estimates are available. Distribution maps of sightings have been developed.

Similar problems are encountered in estimating cetacean population size (species identification and diving behaviour) and these have not been calculated for either bay. Distribution maps of sightings have been provided.

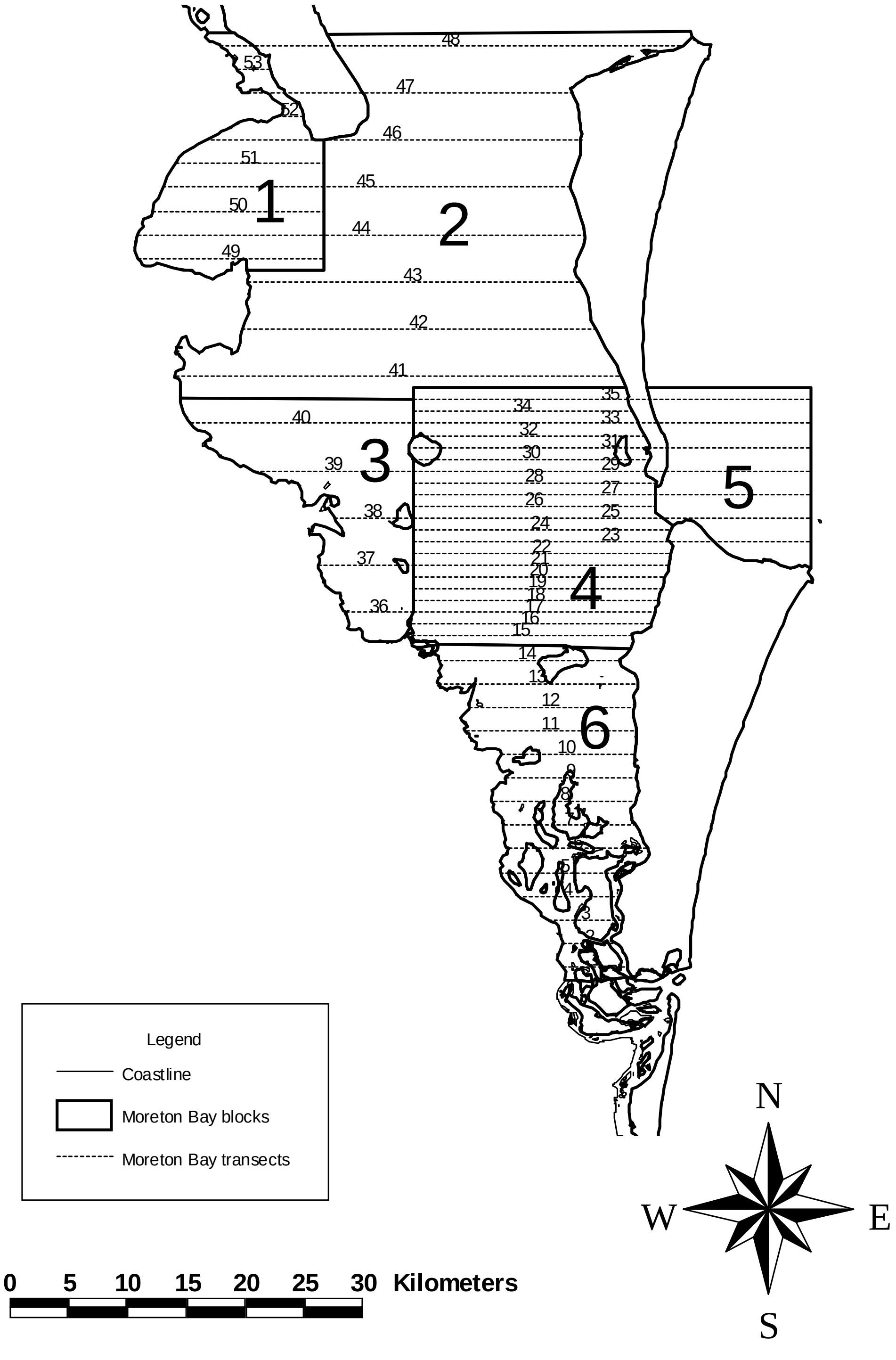

Figure 1a. Blocks and transects in the aerial survey of Moreton Bay

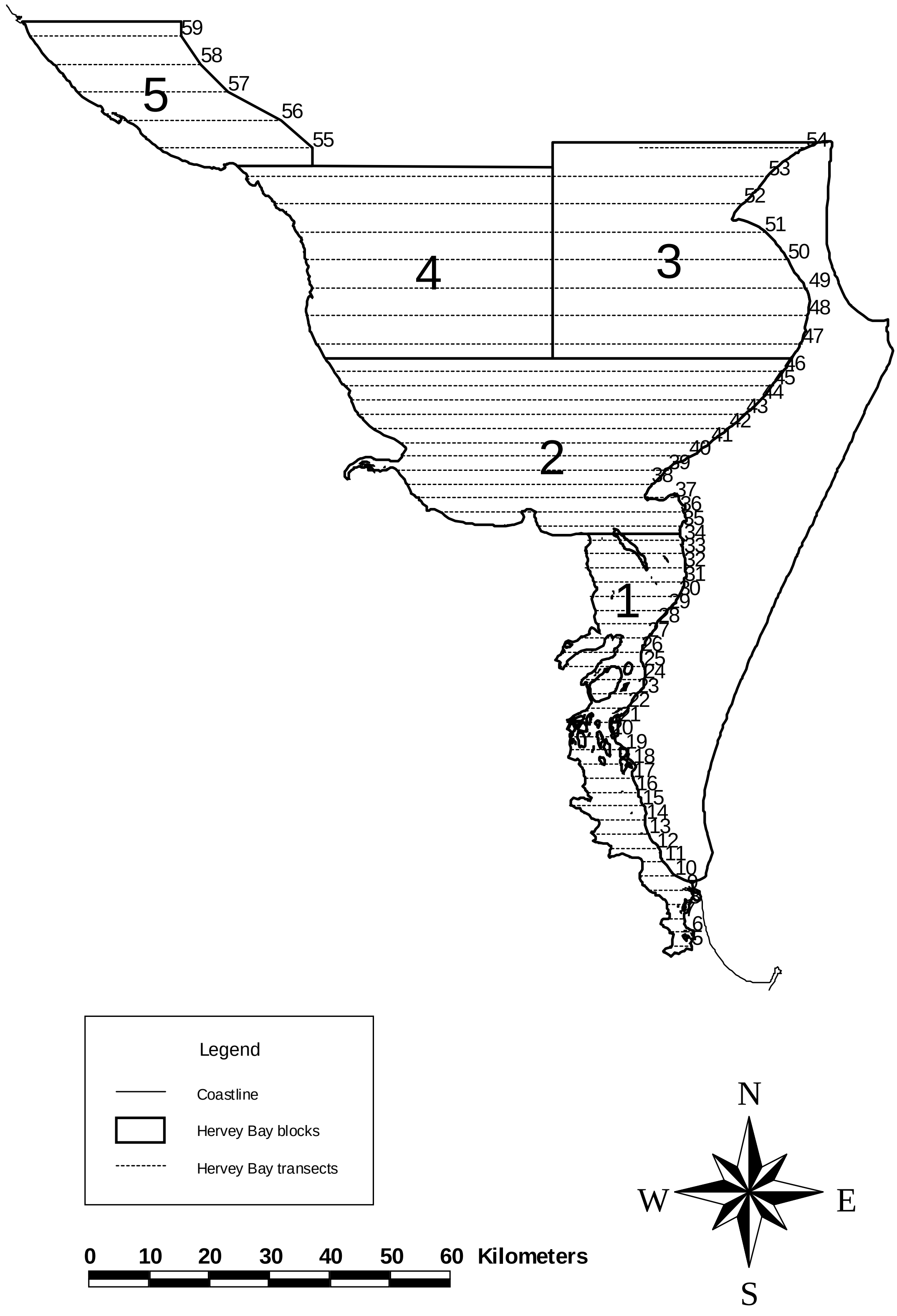

Figure 1b. Blocks and transects in the aerial survey of Hervey Bay

Results

Weather

Weather conditions for the surveys are summarised in Table 2.

December 2000

Weather conditions were marginal for parts of the survey, due to high cloud cover (up to seven oktas of pale grey cloud at approximately 4000 feet in Block 2). Beaufort sea state was three or below for the entire survey.

However, conditions for Block 4, where almost all dugongs and the majority of turtles were sighted, were generally good, with Beaufort sea state usually between one and two. On the first day there was no cloud cover, while on the second day, when it was repeated with four observers, transects 35-25 had cloud between four and six oktas in places with this reduced to almost no cloud cover for transects 24-15. The first estimate for Block 4 (see below) thus acts as a control for the effect of cloud cover in the 2nd estimate. For all transects on both days that Block 4 was surveyed, conditions were such that dugongs could be seen on the bottom.

April 2001

Beaufort sea state was three or below for the entire survey. Cloud cover was high at times during the survey. Despite the cloud, sighting conditions were still quite good in Block 4 of Moreton Bay where again the great majority of dugongs and turtles were sighted. Cloud tended to be highest over the land masses and broken up over the survey area so that conditions were better than our records, taken at the transect ends, indicate. Both dugongs and turtles were clearly visible to the bottom in Block 4 of Moreton Bay.

November 2001

Good conditions were encountered during the survey in November. Cloud clover was a maximum of one okta in Moreton Bay and up to four oktas in Hervey Bay. Beaufort sea state ranged between zero and three.

Table 2. Weather conditions encountered during the survey in comparison to previous surveys of the same areas.
Values for Beaufort sea state and glare are the mean of the modes for each transect.
The range of sea states is given in parentheses.
The scale for glare is: 0 - no glare, 1 - up to 25% of field of view affected by glare, 2 - 25-50% affected, 3 - > 50%

Variable	Moreton Bay				Hervey Bay					
	Nov 2001	April 2001	Dec 2000	1999	Nov 2001	April 2001	1999	1994	1993	1988
Wind speed ($km.h^{-1}$)	<18	<10	<10	<10	<18	<18	<10	<10	<20	<28
Cloud cover (oktas)	0-1	0-6	0-7	0-3	0-4	0-5	0	1-3	1-4	1-6
Minimum cloud height	5000	2500	3000	3500	1500	2000	-	2000-5000	460-1800	610-2400
Beaufort sea state	1.67 (0-3)	1.17 (0-3)	1.92 (1-3)	0.87 (0-3)	1.33 (0-3)	0.65 (0-2)	1.67 (0-4)	1.94 (1-3)	1.2 (0-3)	2.1 (0-4)
Glare –										
North	0.52 (0-2)	1.23 (0-3)	1.36 (0-2)	1.42	1.33 (0-3)	0.96 (0-2)	1.92	0.92		
South	0.52 (0-2)	0.09 (0-2)	1.22 (0-2)	1.23	1.13 (0-3)	0.02 (0-2)	1.86	1.08		
Overall	0.52 (0-2)	0.66 (0-3)	1.29 (0-2)	1.32	1.23 (0-3)	0.49 (0-2)	1.89		1.4	0.9 (0-3)
Visibility (km)	>10	>10	>10	>20	>10	>10	>30	>20	N/A	

Dugongs

Tables 3 and 4 summarise the population estimates for all surveys and give the values of the parameters used in their estimation.

Moreton Bay

December 2000
A total of 184 dugongs were seen in Block 4 on December 12th, with herds of 10, 14, 18 and 70 individuals recorded (Figure 2a). For the remainder of the survey, conducted with four observers, 177 dugongs were seen with one herd of 65 being the only group of more than 10 individuals. Of these, 172 were seen on the repeat survey of Block 4 and the remaining five were outside of that block (Figure 1b).

The proportion of calves in the population was quite low. On December 12th two out of 72 (2.8%) of dugongs in groups of less than 10 individuals were calves. For the remainder of the survey nine out of 112 dugongs (8%) were calves. Calf counts for herds have not been included as it is more difficult to count calves in larger groups and they tend to be underestimated. It is assumed that the proportion of calves in herds is similar to that in smaller groups.

Only in Block 4 were sufficient dugongs seen to generate population estimates. Two dugongs were seen in Block 1, one dugong in each of Blocks 2, 3 and 6 and no dugongs were seen in Block 5.
Two estimates are given for Block 4. These are for the first day with only the data from the mid-seat observers used, and then the second day when data from all four observers are used.

April 2001

A total of 298 dugongs were seen in Moreton Bay, with three herds of 117, 98 and 45 individuals recorded (Figure 2b). Most of the remaining 38 animals were solitary and there were no other groups of more than three animals.

The proportion of calves was 10.7% for all sightings. This may be an underestimate as it includes counts for the large herds, for which it is harder to count all calves. In these cases, the number of calves is an average of the estimates of three observers. It is also notable that the proportion of calves appears higher than in the survey conducted four months earlier in December 2000. This is consistent with comments of all observers that the calves seen were very small.

Only in Block 4 were sufficient dugongs seen to generate population estimates. Three dugongs were seen in Block 2 close to Moreton Island, four in Block 5 and one in Block 6.

November 2001

Four hundred and fifteen dugongs were seen in Moreton Bay, with most of them (356) in herds in Block 4 (herd sizes 28, 42, 46, 85, 155)(Figure 2c). Calves were counted for all sightings except for the herd of 85 in which case the water was too turbid to enable a reliable count. The proportion of calves was 12.4%.

Once again, population estimation was possible only for Block 4. Four dugongs were seen in Block 6, one in each of Blocks 1, 2 and 3.

Differences between surveys of Moreton Bay

Table 4 shows what appears to be an increase in the dugong population of Moreton Bay between April and November 2001. However, this increase is not statistically significant (Table 5).

Table 3. Details of group size estimates and correction factors used in the population estimates for dugongs in the 2000/2001 surveys of the region between Hervey Bay and Moreton Bay.

Area: survey	Group size (C.V)	Number of observers		Perception correction factor estimate (C.V)		Availability correction factor estimate (C.V)
		Port	Starboard	Port	Starboard	
Moreton Bay						
Dec 2000	1.400 (0.629)	1	1	1.119 (0.011)	1.357 (0.015)	1
		2	2	1.037 (0.011)	1.049 (0.015)	1
Apr 2001	1.568 (0.607)	2	2	1.080 (0.024)	1.134 (0.041)	1
Nov 2001	1.229 (0.633)	2	2	1.034 (0.020)	1.046 (0.039)	1
Hervey Bay						
Apr 2001	1.286 (0.485)	2	2	1.080 (0.024)	1.134 (0.041)	1.917 (0.200)
Nov 2001	1.486 (0.742)	2	2	1.034 (0.020)	1.046 (0.039)	1.885 (0.156)

Table 4. Estimates of dugong numbers for each survey block in the region between Hervey Bay and Moreton Bay

Block	1988 Population (s.e.)	1992 Population (s.e.)	1993 Population (s.e.)	1994 Population (s.e.)	1999 Population (s.e.)	Dec 2000 Population (s.e.)	Apr 2001 Population (s.e.)	Nov 2001 Population (s.e.)
Moreton Bay				**1995**[1]				
1				0-8 (5)	15 (14)	-	-	-
2				0-13 (11)	Not surveyed	-	-	-
3				0-20 (27)	30 (32)	-	-	-
4				167 (21) – 806 (348)	Not surveyed	344 (88)	366 (41)	493 (45)
5				0 – 178 (143)	Not surveyed	-	-	-
6				0 – 68 (58)	126 (67)	-	-	-
Total				366 (159) – 896 (201)	171 (76)[2]	344 (88)[3]	366 (41)	493 (45)
Hervey Bay								
1	269 (147)	943 (377)	168-218 (52)	287 (79)	373 (96)		416 (68)	446 (112)
2	1753 (388)	71 (40)	257 (85)	408 (115)	875 (196)		348 (110)	1263 (375)
3	151 (55)	21 (22)	22 (21)	49 (50)	113 (71)		155 (68)	-
4	33 (32)	74 (50)	74 (74)	31 (22)	112 (76)		-	-
5				32 (21)	180 (53)		Not surveyed	-
Total		1109 (383)	579-629 (126)	807 (151)	1654 (248)		919 (146)	1708 (392)

[1] Data from estimates made over 6 bi-montly surveys in 1995 by Lanyon and Morrice (1997) using slightly different methodology (see discussion for details)
[2] Survey not completed due to poor weather conditions
[3] Note that Moreton Bay Block 4 was also surveyed, with only two observers, the day prior to this estimate. The resulting estimate was 344 (68).

Table 5. Split-plot analysis of variance examining dugong density among surveys. Estimated variances (Est. Var.) are from a variance components analysis.

Term	**SS**	**df**	**MS**	**Est. Var.**	**F**	*P*
Transect[3]	42.68	20	2.13	~0.00001		
Year[1, 2]	5.08	2	2.54		1.13	0.335
Error	90.27	40	2.26	2.216		

[1]Tested against year by transect interaction (i.e. error)
[2] Fixed factor
[3] Random factor

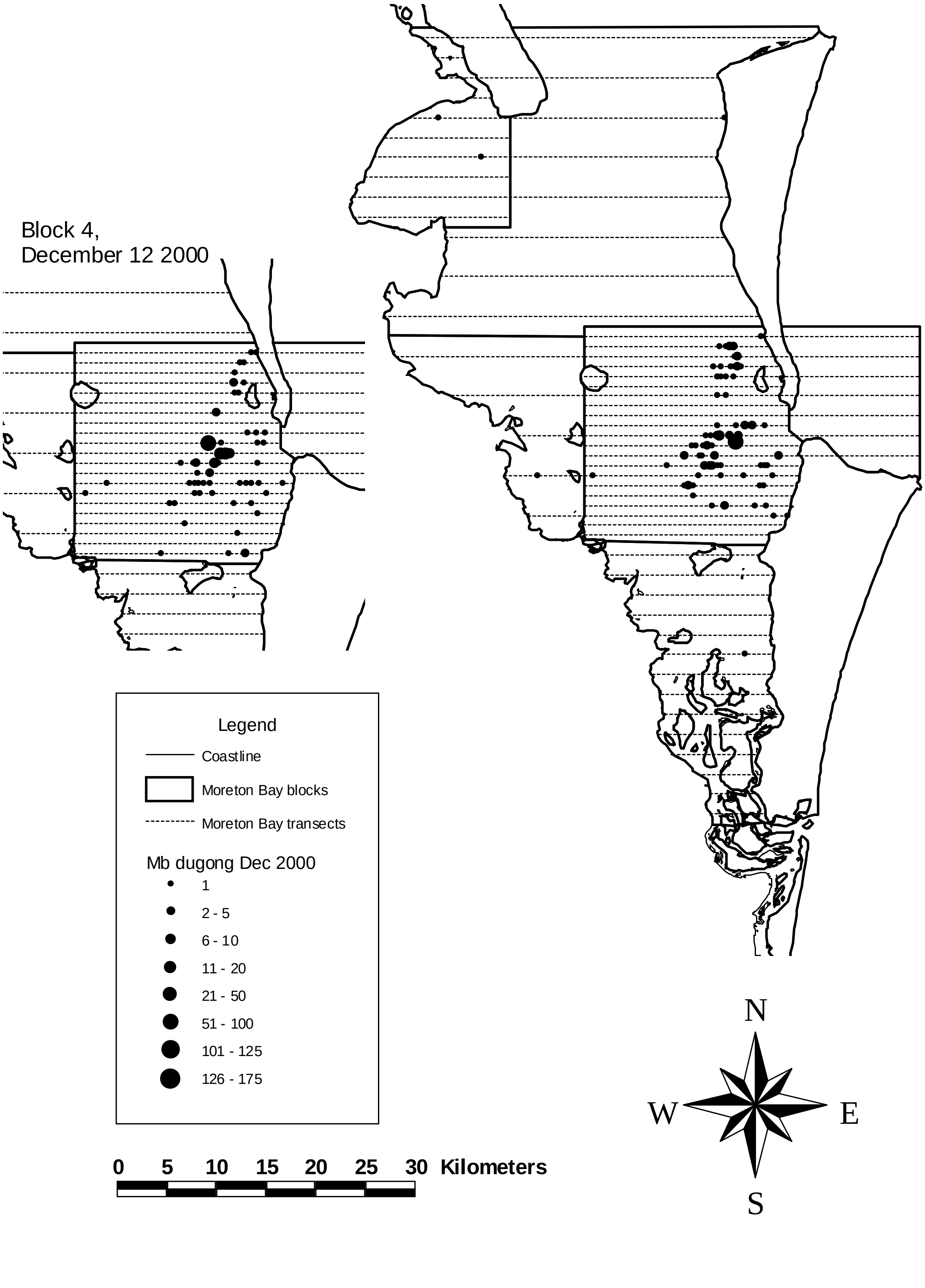

Figure 2a. Distribution of dugong sightings during the December 2000 survey of Moreton Bay

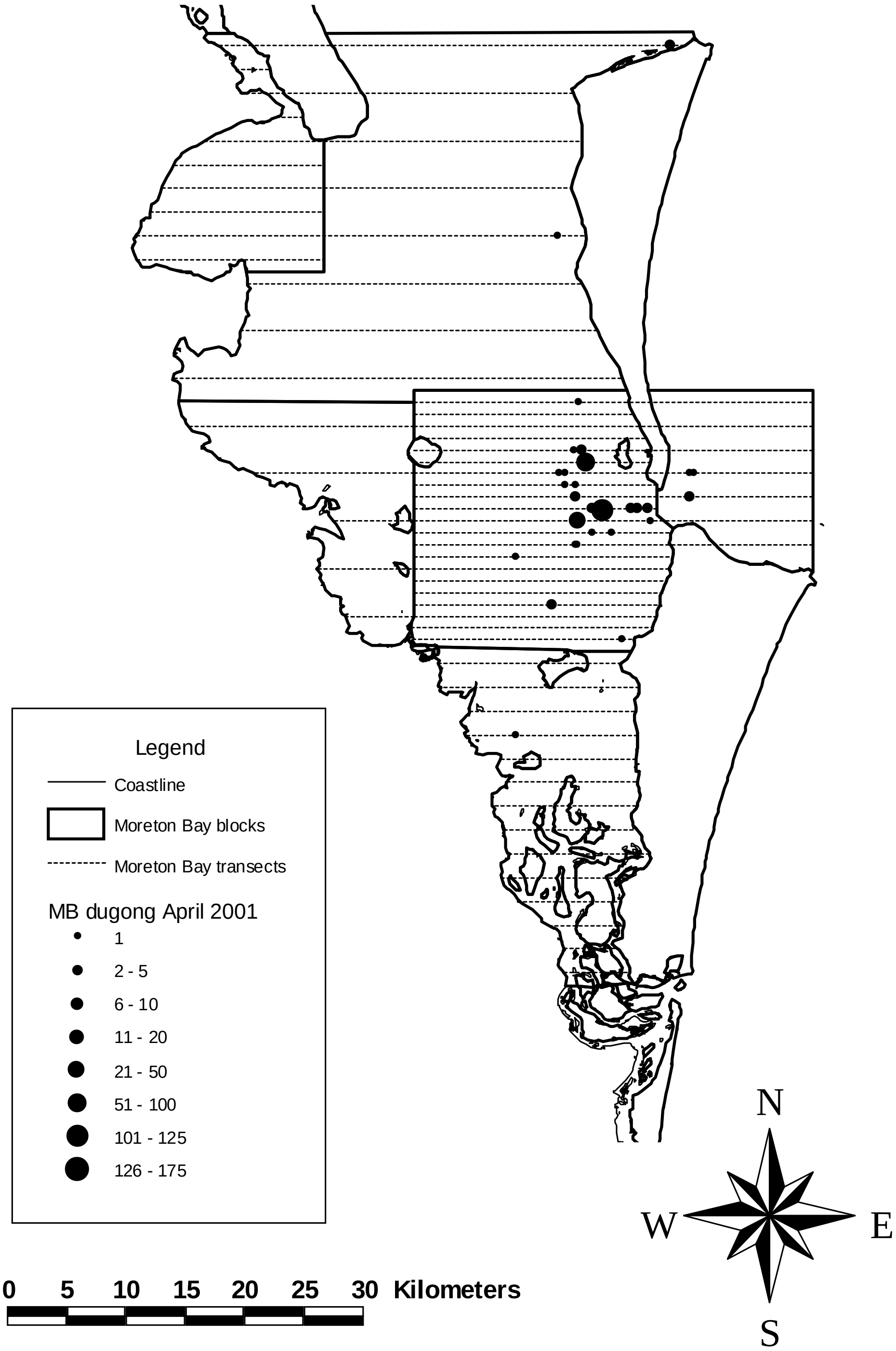

Figure 2b. Distribution of dugong sightings during the April 2001 survey of Moreton Bay

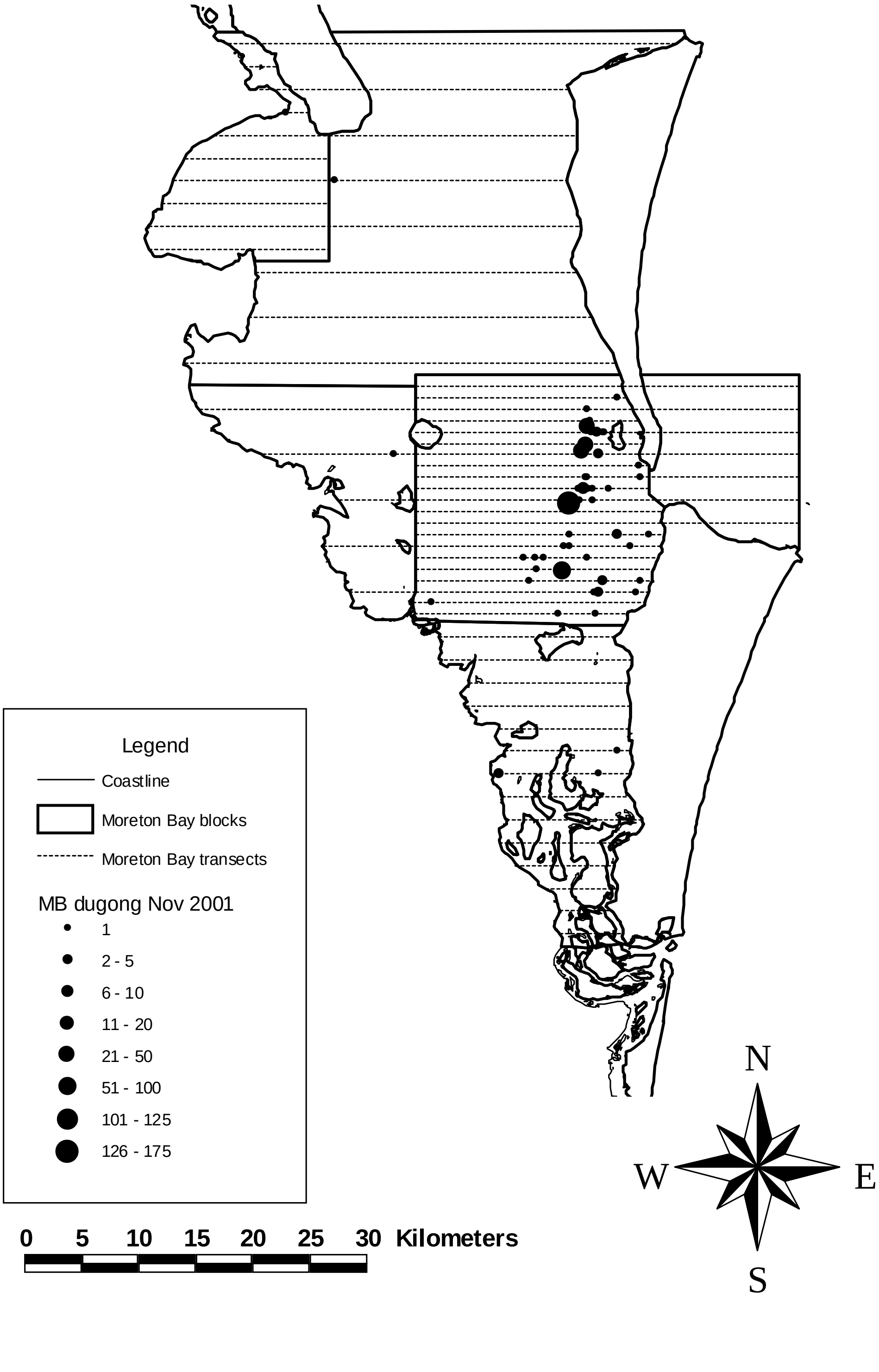

Figure 2c. Distribution of dugong sightings during the November 2001 survey of Moreton Bay

Hervey Bay
<u>April 2001</u>

Ninety four dugongs were seen in Hervey Bay (Figure 3a). All were in small groups (less than four) except for a herd of 23 animals near Burrum Heads. The proportion of calves was 8.5%.

Population estimates have been made for Blocks 1-3 but only one dugong was seen in Block 4 and Block 5 was not surveyed due to poor weather.

<u>November 2001</u>

One hundred and fifty six dugongs were seen in Hervey Bay (Figure 3b), thirteen (8.3%) of them calves. The largest group was of eight individuals.

No population estimates have been made for Blocks 4 and 5 (no dugongs sighted) or for Block 3 where only four groups were seen.

<u>Differences between surveys of Hervey Bay</u>

Hervey Bay was surveyed in November 1999 (Lawler and Marsh 2000), April 2001 and November 2001. Five blocks were surveyed in each year with the exception that Block 5 was not sampled in April 2001. No dugong were recorded in Block 5 in November 2001. Block 5 was not included in subsequent analyses as it provided no information on changes in density during 2001.

There was no evidence for changes in dugong density among years or among blocks over time (Table 6). The large components of variance were among block variance and the error variance (i.e. among transects within blocks over time), indicating substantial variability in dugong density between blocks and among transects over time. The among block variability was about a third that of the error variance.

Table 6. Split-plot analysis of variance examining dugong density among surveys. Estimated variances (Est. Var.) are from a variance components analysis.

Term	SS	df	MS	Est. Var.	F	*P*
Block[3]	45.5	3	15.17	0.414		
Transect (Block)[3]	75.1	53	1.42	0.062		
Year[1, 2]	3.04	2	1.52		0.68	0.542
Year*Block[3]	13.4	6	2.23	0.085	1.80	0.106
Error	131.4	106	1.24	1.233		

[1]Tested against year by block interaction
[2] Fixed factor
[3] Random factor

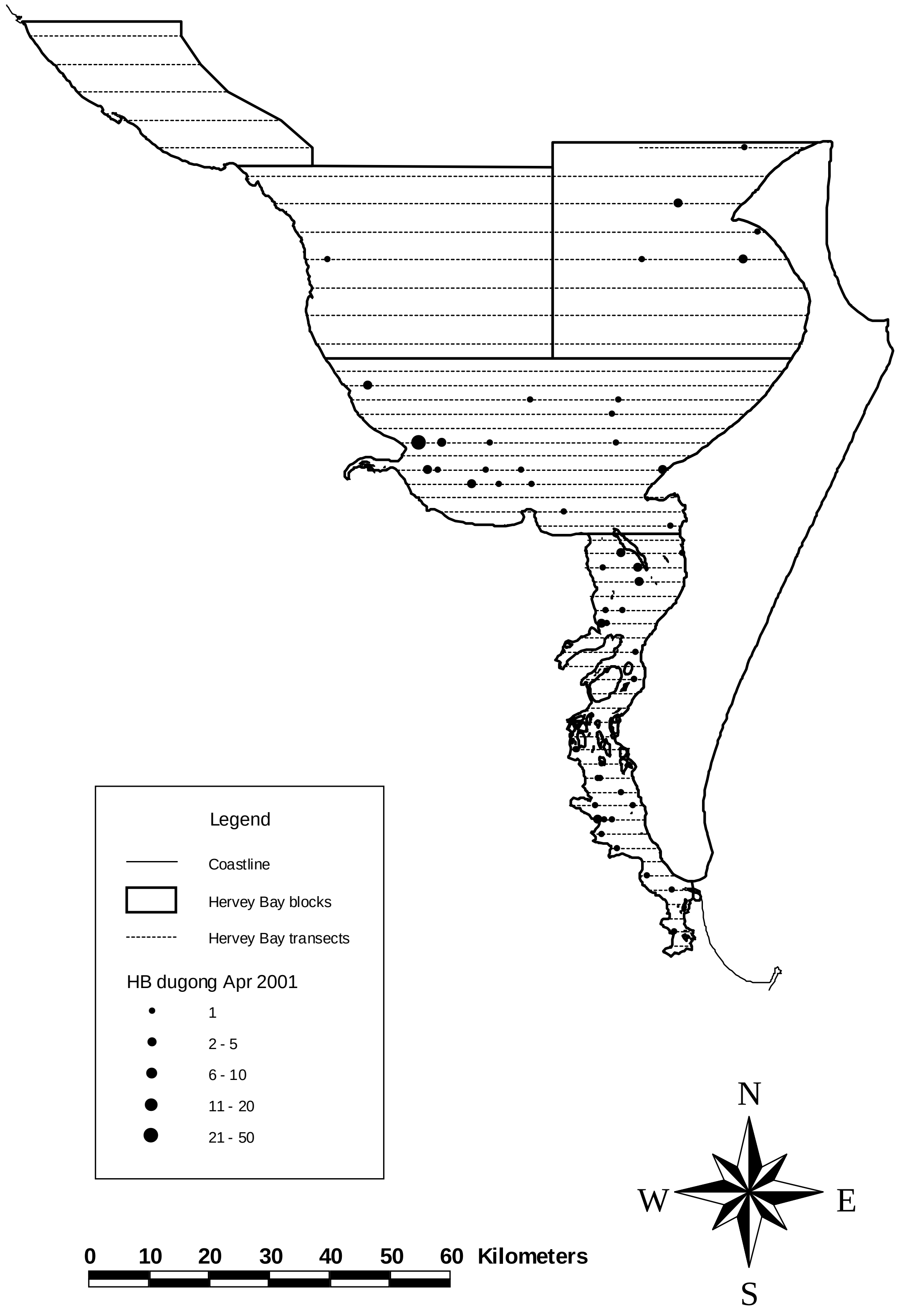

Figure 3a. Distribution of dugong sightings during the April 2001 survey of Hervey Bay

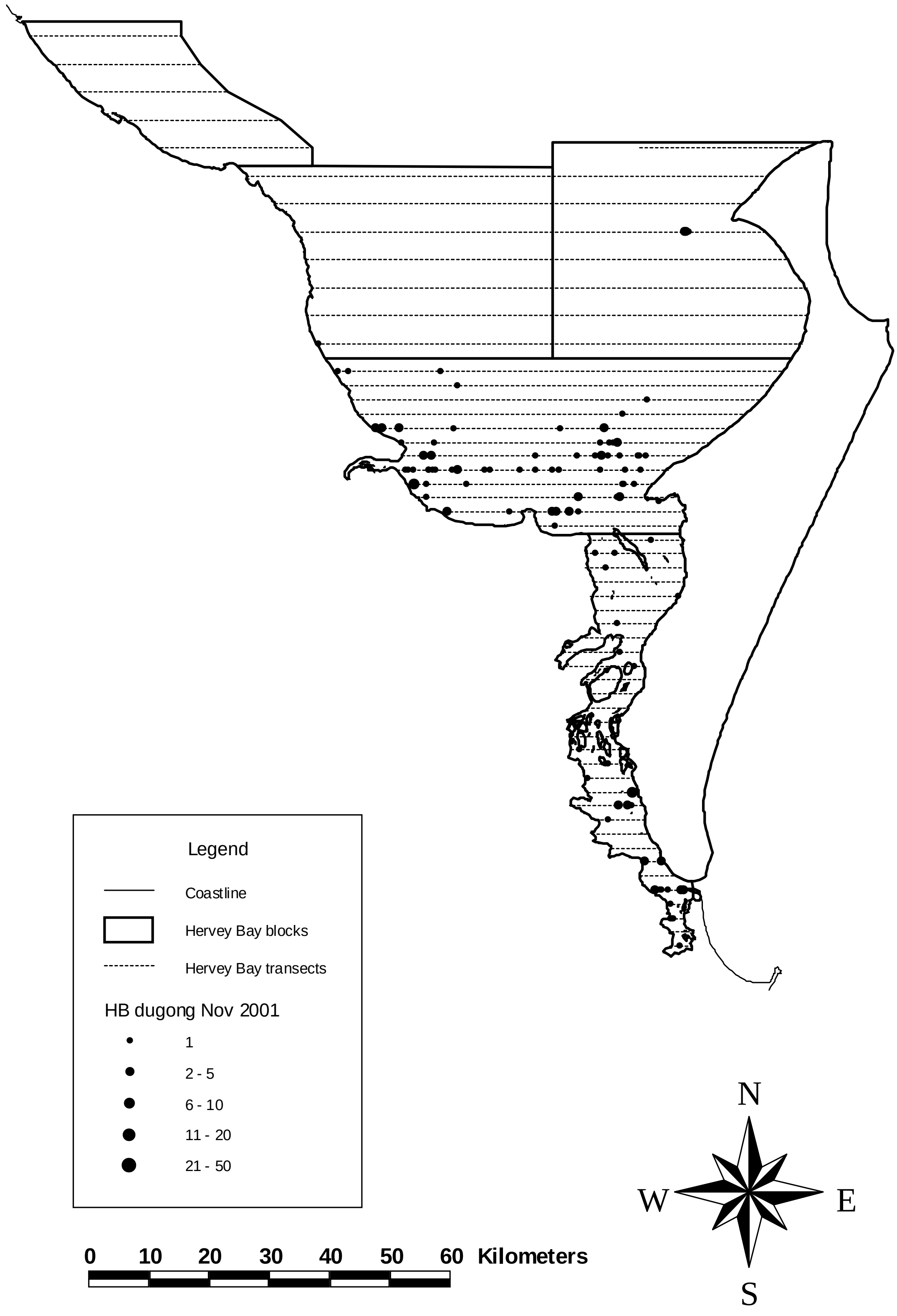

Figure 3b. Distribution of dugong sightings during the November 2001 survey of Hervey Bay

Turtles

Moreton Bay

Table 7 summarises the population estimates for all surveys (of Moreton Bay only) and gives the values of the parameters used in their estimation.

<u>December 2000</u>

Three hundred and twenty one turtles were seen in Moreton Bay during the survey, 263 of which were in Block 4 (Figure 4a). Population estimates for turtles were made in the same manner as for dugongs. There were insufficient sightings to make estimates in Blocks 3 and 5. While turtles do not form herds in the same manner as do dugongs, there were at times very dense aggregations for which it was difficult to enter data separately for each individual sighting. The counts for these groups have been treated in the same way as dugong herds in the analysis.

<u>April 2001</u>

Over 550 turtles were seen in Moreton Bay during the survey, 484 of which were in Block 4 (Figure 4b).

Note that for turtles I have followed the procedure for use of availability correction factors for Block 4 as described above for dugongs. That is, the majority of turtles in Block 4 were seen in water where the bottom was clearly visible. I have thus used no availability correction factor for this block. For all other blocks I have used a correction factor based on the pooled data for these blocks as per Table 2.

<u>November 2001</u>

Three hundred and forty six turtles were recorded in Moreton Bay in November 2001 (Figure 4c). As with the earlier surveys they were found predominantly in Block 4, but were also common throughout the remainder of the bay.

Hervey Bay

<u>April 2001</u>

Three hundred and thirty six turtles were seen in Hervey Bay during the survey (Figure 5a). They were found in all blocks, but tended to be more common in the shallower regions of the south and east of the bay and in the Sandy Straits.

<u>November 2001</u>

Three hundred and twelve turtles were seen in Hervey Bay in November 2001, with distribution similar to that described above for the April survey (Figure 5b).

Table 7. Details of group size estimates and correction factors used in the population estimates for turtles in the 2000/2001 surveys of Moreton Bay.

	December 2000	**April 2001**	**November 2001**
Mean group size	1.262 (0.743)	1.823 (0.899)	1.242 (0.560)
Availability correction factor	1.391 (0.127)	2.137 (0.143)	1.425 (0.104)
Perception correction factors			
Port	1.059 (0.018)	1.087 (0.015)	1.116 (0.017)
Starboard	1.127 (0.043)	1.116 (0.074)	1.198 (0.038)
Population estimates			
- Block 1	186 (52)	194 (88)	279 (89)
- Block 2	381 (120)	358 (247)	510 (97)
- Block 3	n/a	215 (142)	180 (86)
- Block 4	582 (98)	805 (128)	601 (92)
- Block 5	n/a	-	-
- Block 6	42 (21)	299 (152)	155 (62)
- **Total**	**1191 (165)**	**1871 (358)**	**1124 (192)**

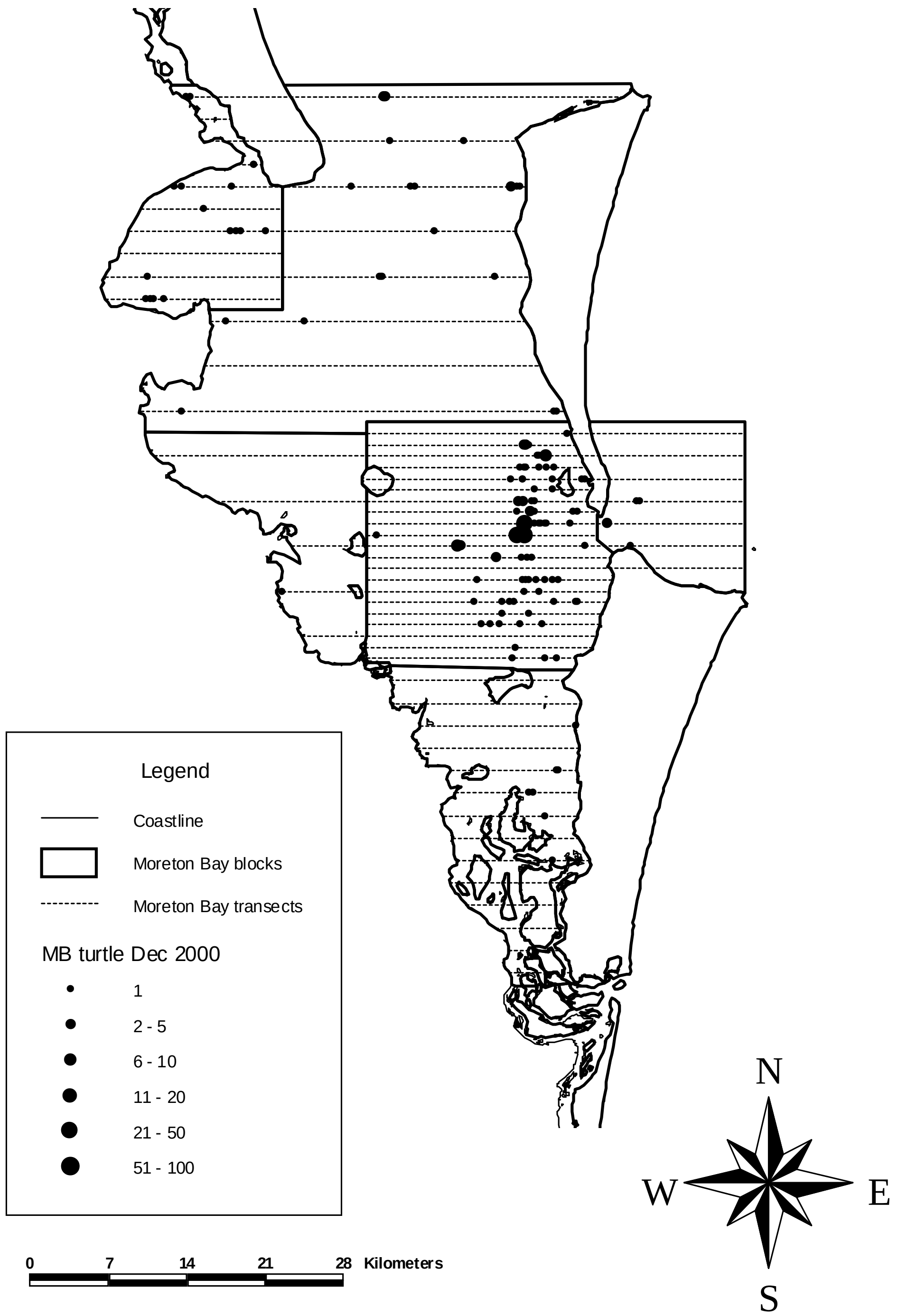

Figure 4a. Distribution of turtle sightings during the December 2000 survey of Moreton Bay

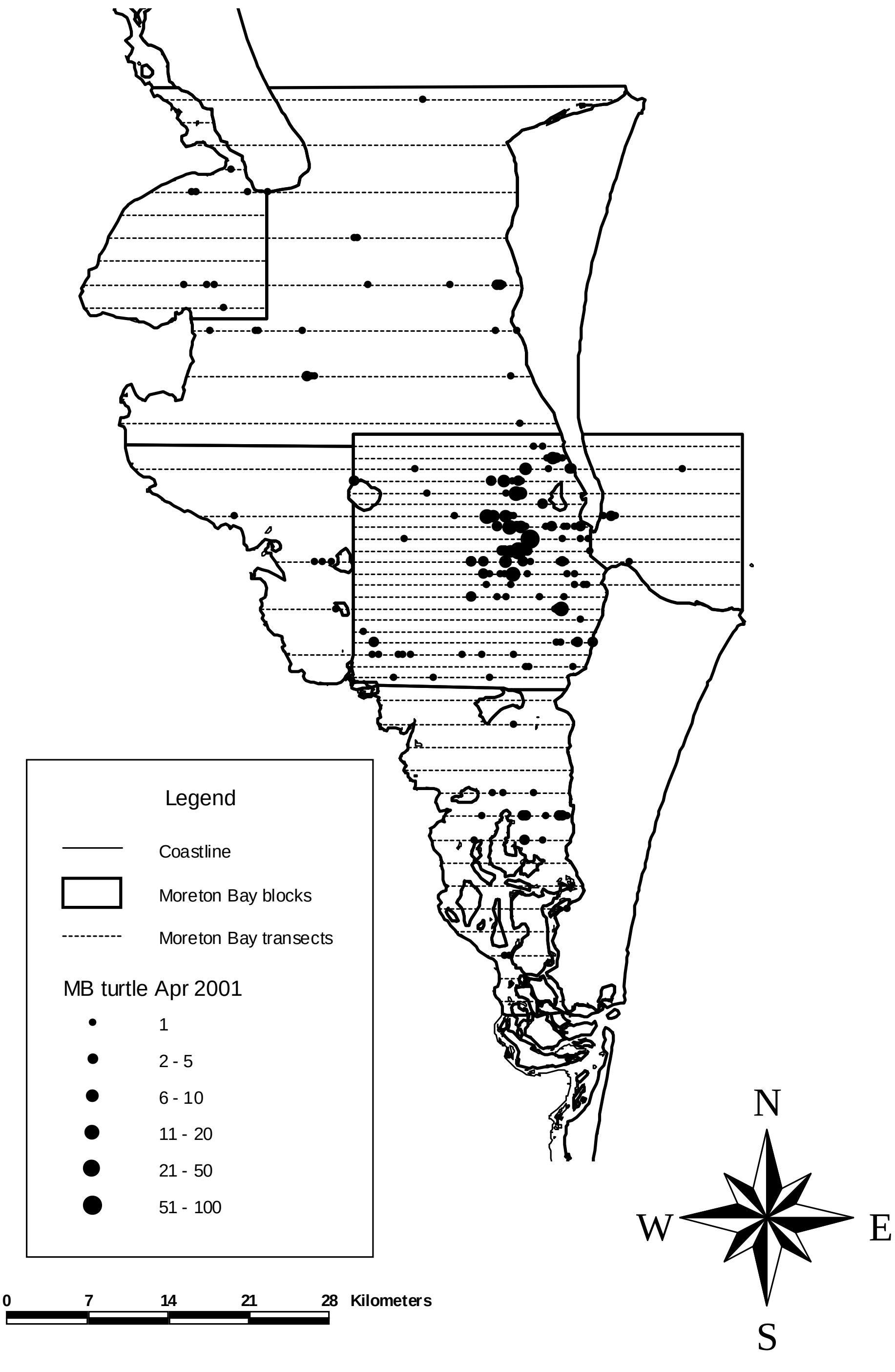

Figure 4b. Distribution of turtle sightings during the April 2001 survey of Moreton Bay

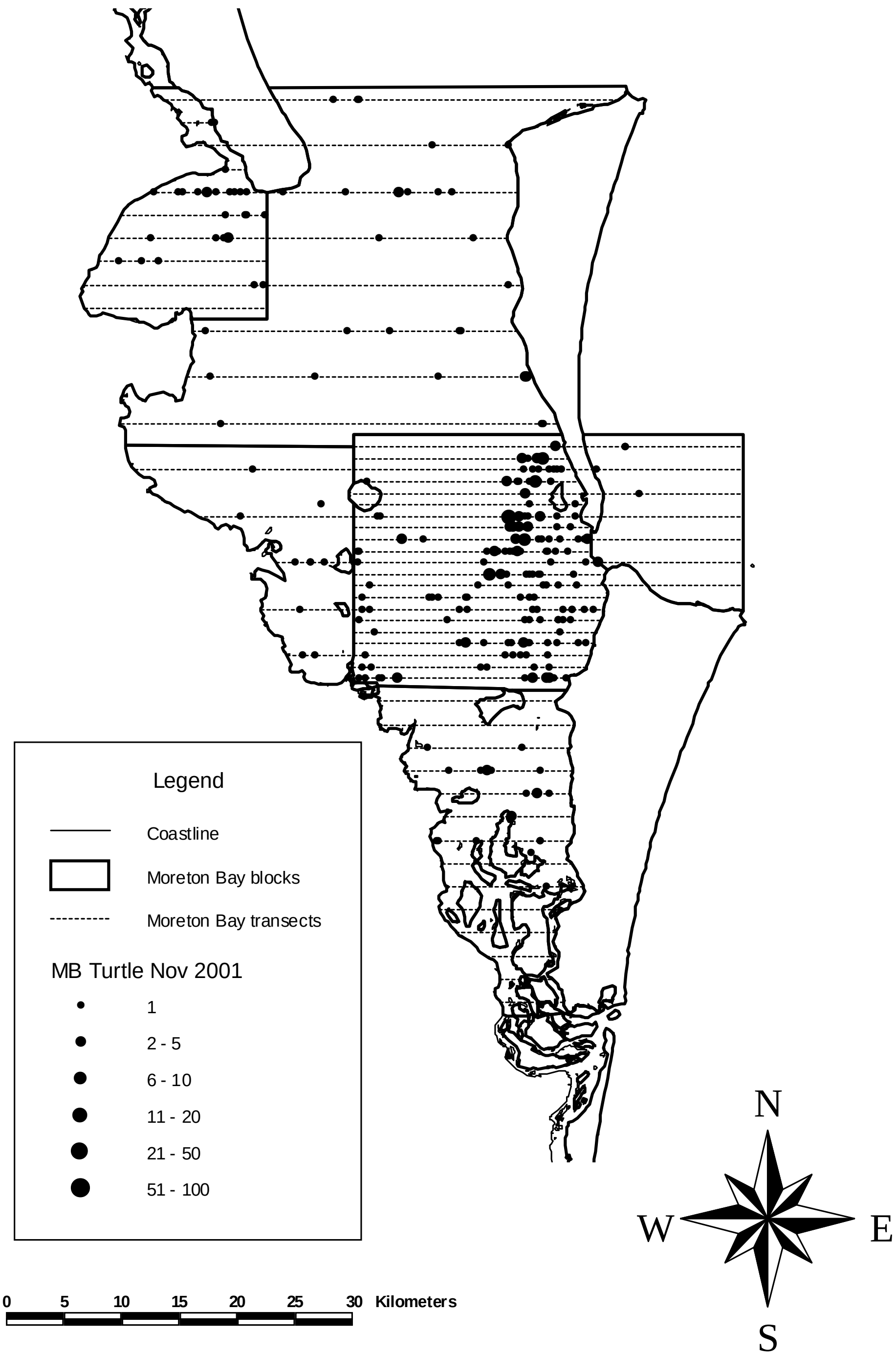

Figure 4c. Distribution of turtle sightings during the November 2001 survey of Moreton Bay

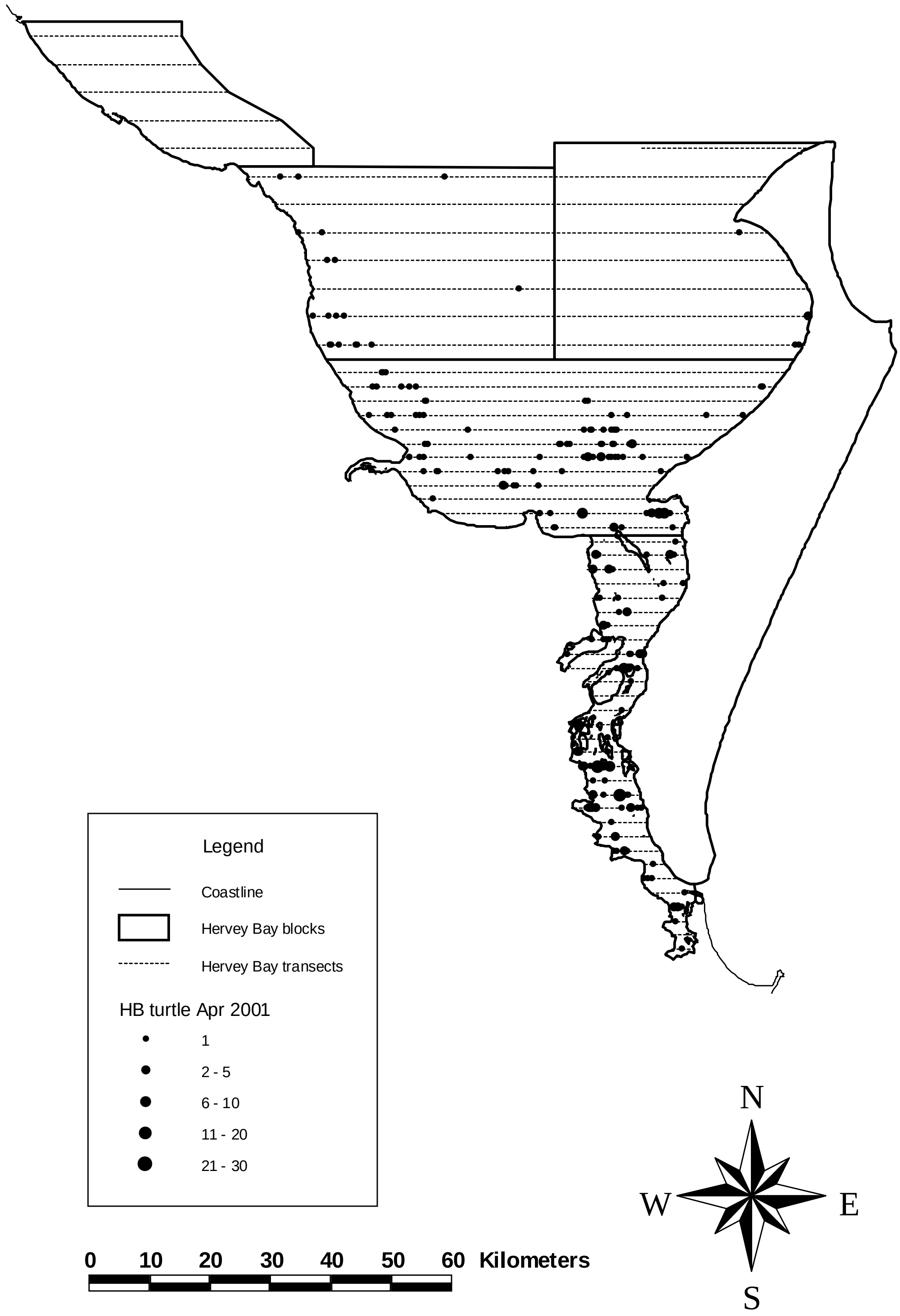

Figure 5a. Distribution of turtle sightings during the April 2001 survey of Hervey Bay

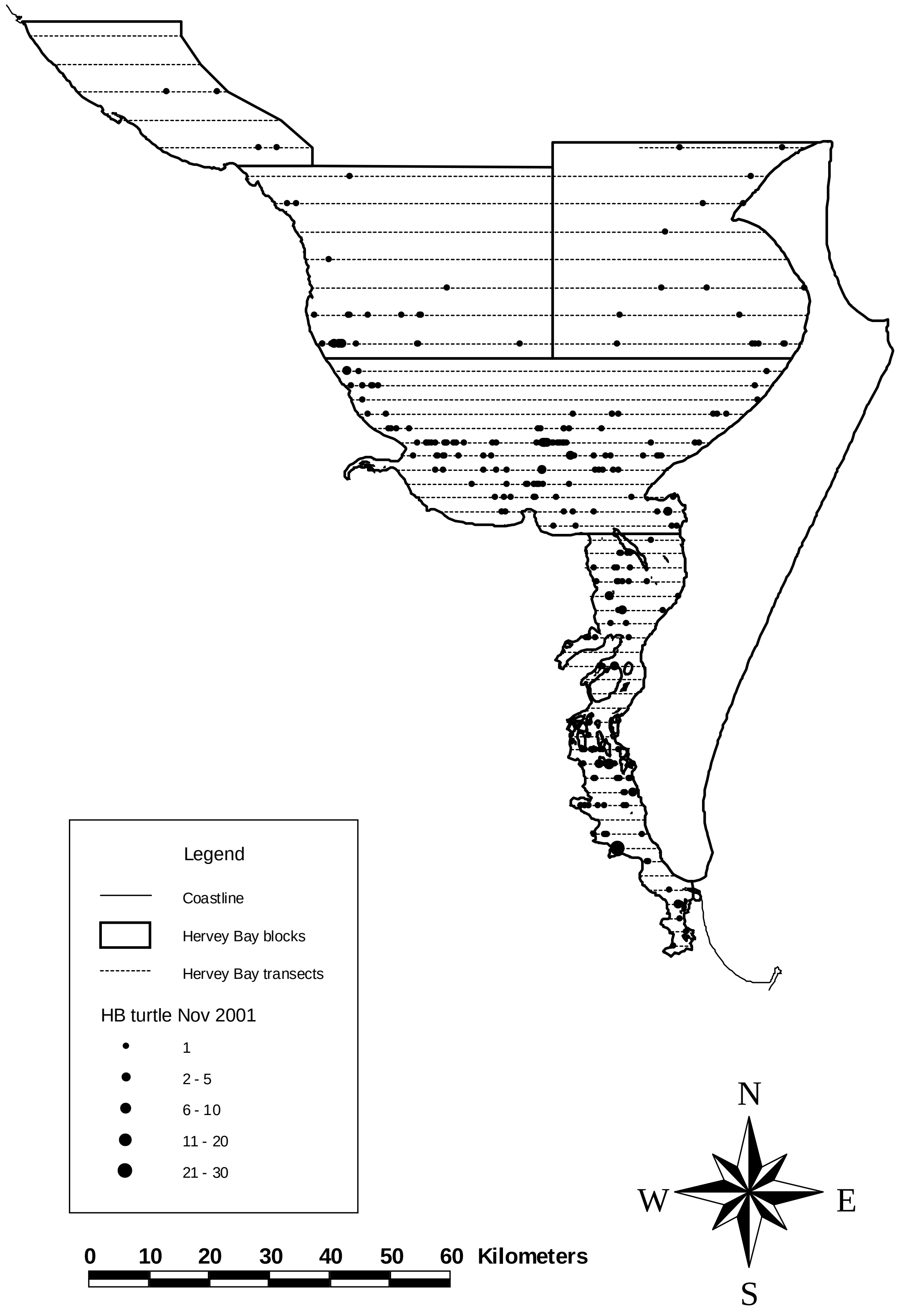

Figure 5b. Distribution of turtle sightings during the November 2001 survey of Hervey Bay

Cetaceans

Moreton Bay

<u>December 2000</u>

There were only nine separate sightings of dolphins throughout the survey with a total of 24 animals (Figure 6). The largest group was of 12 individuals. There are insufficient data to estimate populations for cetaceans.

<u>April 2001</u>

There were eight separate sightings of dolphins throughout the survey with a total of 18 animals (Figure 6). The largest group was of four individuals. Only one calf was seen.

<u>November 2001</u>

There were 27 sightings of dolphins, totalling 48 animals in November 2001 (Figure 6). The maximum group size was of seven animals and the total number of calves seen was five.

Hervey Bay

<u>April 2001</u>

Thirty sightings of dolphins were made in Hervey Bay with a total of 81 animals (Figure 7). The largest group was of nine animals. Twelve animals were calves.

<u>November 2001</u>

There were 33 sightings of dolphins in Hervey Bay (Figure 7) with a total of 59 animals of which five were calves. The largest groups were two groups of nine animals.

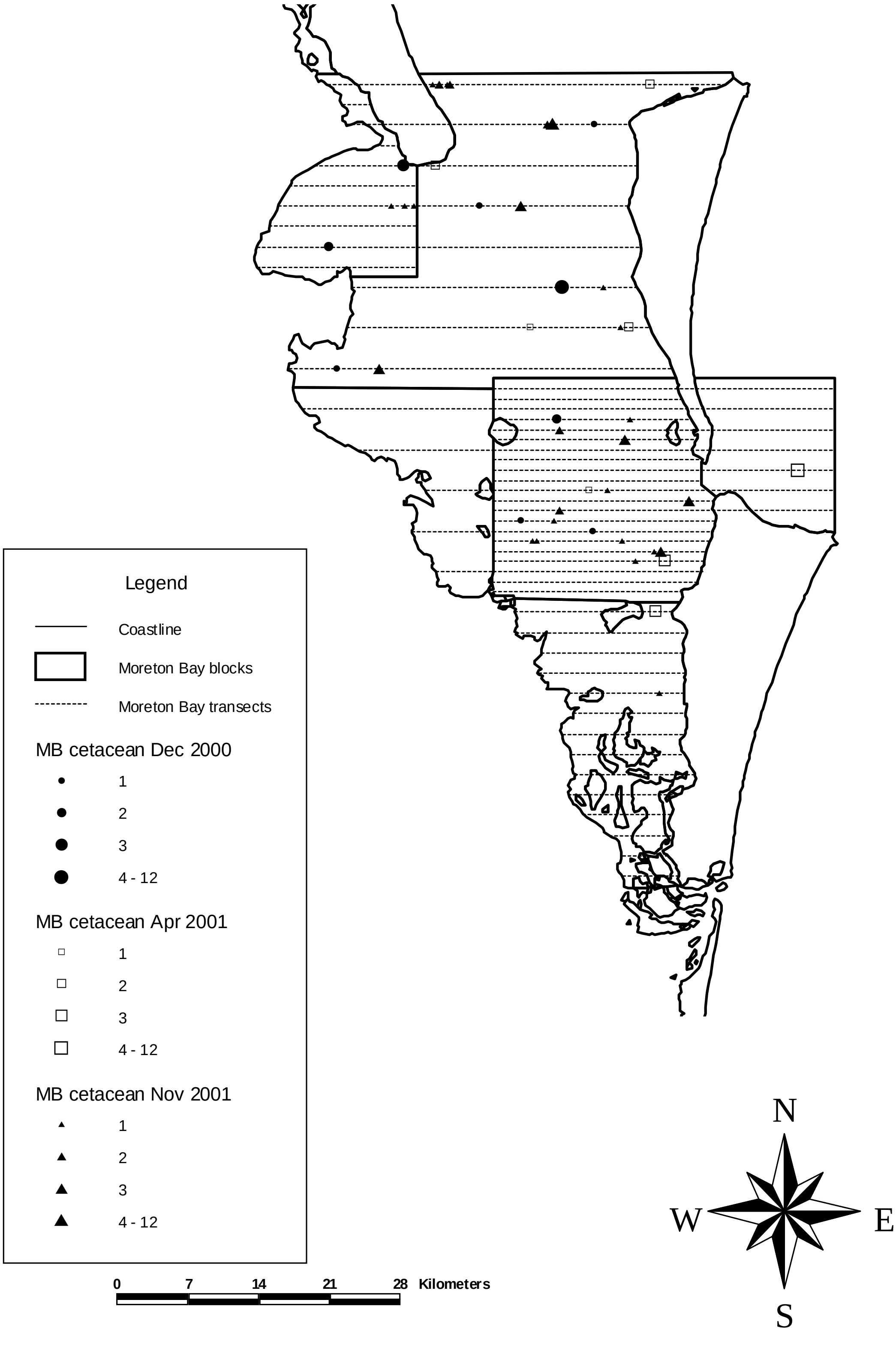

Figure 6. Distribution of cetacean sightings during the surveys of Moreton Bay

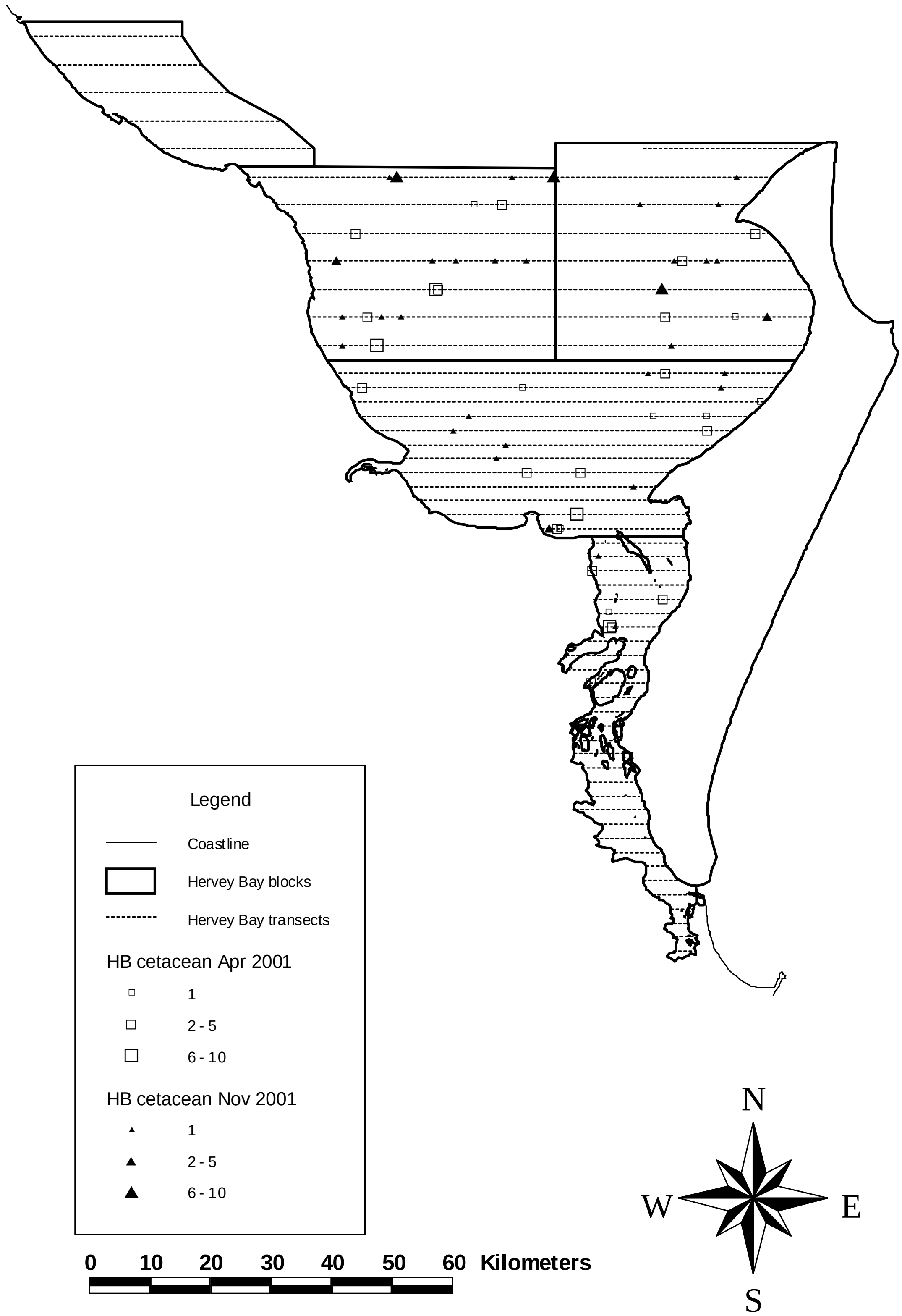

Figure 7. Distribution of cetacean sightings during the surveys of Hervey Bay

Discussion

The data presented above provide updated estimates of the dugong population of Moreton Bay and Hervey Bay consistent with the methodology employed extensively throughout the adjoining Queensland coastline and extending into the Northern Territory and Western Australia. Thus these estimates are now comparable with estimates made in those regions. This is particularly important given the now widely accepted hypothesis that dugong populations on the bay scale are inherently unstable due to the large scale movements made by substantial numbers of individuals often within relatively short periods of time.

These data provide some evidence of such changes in the dugong populations of the two bays, but also serve to highlight two additional factors. Firstly, the inconsistency of survey methodologies employed in Moreton Bay in the past with those used elsewhere (and used in this study) reduces the capacity to assess such changes. In the context of what is now known about dugong movements, future surveys should be conducted using standardised methodology. In fact, the scale of future surveys should be expanded to include at least adjacent Hervey Bay, but optimally would be timed so as to coincide with the regular surveys of the southern Great Barrier Reef Marine Park. Secondly, these results highlight an inherent problem with attempts to monitor trends in wildlife populations via surveys, that of a lack of statistical power (Taylor and Gerrodette 1993, Marsh 1995). Despite an increase in the mean estimate for Moreton Bay between April and November 2001 of some 127 animals (approximately 35%) this was still insufficient to be statistically significant.

Although assessment of the effects of *Lyngbya* was the primary impetus for undertaking this study, the absence of a substantial outbreak during the study period has meant that the focus of the study has changed. Consequently, the order of topics in the following discussion reflects this changed focus. I begin by discussing the likelihood and importance of movements to dugong populations, particularly in Moreton Bay, followed by a consideration of the changing methodologies used in surveying Moreton Bay and finish with consideration of the effects of *Lyngbya* on the Moreton Bay dugong population.

Differences in survey estimates of the dugong population of Moreton Bay

One of the significant outcomes of the first survey conducted in this research project was that the estimated dugong population in December 2000 was lower than the estimates made in 1995 (Lanyon and Morrice 1997) and this was perceived by some as a decline in the dugong population of Moreton Bay.

Before going on to consider this, and other (see below), possible reasons for the apparent decline, it worthwhile first to consider the scale of the change in the context of other previous estimates of the dugong population of Moreton Bay (Table 8). Despite great differences in methodology, it has long been held (for over 100 years) that the population of dugongs in Moreton Bay numbers in the several hundred. While the mean estimates cited in this study are lower than those of Lanyon and Morrice (1997) it should be noted that the latter are by far the highest estimates for the region. The highest uncorrected (raw) count of Lanyon and Morrice (1997) of 847 dugongs was nearly 28% higher than the next highest count made by Preen and Marsh in 1993 (Table 6). The most appropriate comparative estimate to this study is that of Marsh et al. (1990) who used the same survey technique (but lower survey intensity over the eastern banks region). Their estimate of 458 (±78) is remarkably similar to the final population estimate in this study (November 2001 - 493±45). What should also be noted from Table 8 is that, even within studies where methodology is thus consistent, there is substantial variation in the counts (e.g. Lear 1977,Preen 1993, Lanyon and Morrice 1997). Overall, while there are considerable difficulties in comparing estimates, particularly where the methodologies used are different, the current estimates are well within the range recorded previously for Moreton Bay. If there has been any decline (and it is not possible to conclude this with any statistical confidence) it is not possible to assess its importance without considering data other than that from aerial surveys (e.g. seagrass abundance, dugong mortality).

Nevertheless, the *apparent* decline in the dugong population of Moreton Bay between 1995 and 2000 caused considerable concern among managers of the bay and was thus the impetus for the project objectives to be modified such that Hervey Bay was included in the 2nd and 3rd surveys. The basis for that decision was my interpretation, in the preliminary report for the December 2000 survey, that the most likely explanation for the reduced numbers was the movement of dugongs out of Moreton Bay with Hervey Bay, the nearest significant dugong habitat, being a likely destination.

There are other explanations for the result, which are not mutually exclusive. These are that the marginal sighting conditions in the first survey lead to an underestimate in numbers and/or that it was due to the differences in methodology between this project and the previous project assessing dugong numbers in Moreton Bay (Lanyon and Morrice 1997). Each of these possibilities is addressed below.

Table 8. Summary of previous estimates of Moreton Bay dugong population

Date	Estimated number	method	Source
Late 1800s	300-400	Informal boat survey	Welsby (1905)
1976-77	118-283	Standardised aerial survey – no correction factors	Lear (1977)
1979	307	Perimeter survey with some transects over eastern banks	Heinsohn and Marsh (1980)
1988-1990	201-569	Standardised aerial survey – no correction factors	Preen (1993)
1988	458 (±78)	Standardised aerial survey with correction factors	Marsh et al. (1990)
1993	664	Standardised aerial survey – no correction factors, as per Preen (1993)	Preen and Marsh (1995)
1995	366 (±159)-896(±201)	Standardised aerial survey with correction factors. Design as per this study but flown at 274m altitude	Lanyon and Morrice (1997)
2000-2001	344 (±88)- 493 (±45)	Standardised aerial survey with correction factors – see methods for design	This study

Movements of dugongs

There is an increasing body of evidence that dugongs move over large distances as a common aspect of their behaviour (Lawler et al. 2001). Repeat aerial surveys, over areas well in excess of that covered by Moreton Bay, show that dugong populations fluctuate by amounts that exceed the capacity of local populations to increase by breeding alone (Marsh et al. 1997, Marsh and Lawler 2001)(Table 9). In addition, satellite tracking studies have shown that the majority of dugongs move distances in excess of 80km in tracking periods averaging 2-3 months, some travelling distances up to 600km in a few days (Preen 1999, Lawler et al. 2001, Preen 2001). The time-frame under which such movements may be made is clearly much smaller than the period between most repeat aerial surveys.

Movements such as this would be expected in a large herbivore that feeds on a resource that may fluctuate in abundance over large scales (Preen and Marsh 1995, Preen et al. 1995a, Poiner and Peterken 1996). Whether factors other than food availability determine these movement patterns is currently unknown. However, what this demonstrates is that when monitoring of a single bay shows fluctuations in the dugong population, it is not *necessarily* cause for real concern. In fact, it would be surprising if the dugong population of Moreton Bay was constant over periods of years or even months. In response to these concerns, senior managers at the Great Barrier Reef Marine Park Authority have advocated extending aerial survey programs to cover very large areas (e.g. entire east coast of Queensland, including Torres Strait) to avoid problems of confounding movements with stock assessments.

Table 9. Evidence for movements of dugongs from aerial surveys over large scales.

Region	**Evidence of significant change in dugong abundance suggested by standardised aerial surveys**		**Likely reason for change**
	Date	*Population estimate ± s.e*[1].	
Torres Strait Qld	1987	13,319 ± 2,136 a	Unknown
(Marsh *et al* 1997 a, 1997b,	1991	24,225 ± 3,276 a	.
unpublished)	1996	27, 881± 3,216 b	
	2001	14, 106 ± 2314	
Southern GBR Qld	1986/87	3,479 ± 459 a	Unknown
(Marsh *et al*. 1996, Marsh and	1992	1,857 ± 292 b	
Lawler 2001)	1994	1682 ± 236 b	
	1999	3993 ± 641 a	
Hervey Bay Qld (blocks 1-4)	1988	2206± 420	Seagrass loss
(Preen and Marsh 1995; Marsh	1992	1109±383	in 1992 after
et al. 1996, Marsh and Lawler	1993	521-571±126	episodic disturbance
2001, this study)	1994	775±150	
	1999	1473± 242	
	2001 (Nov)	1708 ± 392	
Shark Bay	1989	10,146 ± 1,665a	Seagrass loss in Exmouth
(Marsh *et al*. 1994; Preen *et*	1994	10,529 ± 1,464a	Gulf after episodic
al.1997, Gales pers comm.,	1999	13,929 ± 167	disturbance in 1999
Holley and Lawler *unpublished*)	2002	11,020 ± 1288	
Exmouth Gulf	1989	1, 062 ± 321a	Seagrass loss in Exmouth
*(*Preen *et al*.1997, Gales *pers*	1994	1,006 ± 494a	Gulf after episodic
comm.. 2001; Prince *et al*. 2001)	1999	337 ± 108	disturbance in 1999
	2000	too small to estimate	Time x Block Interaction significant for 1989-94 Comparison; 1999 –2000 comparisons n.a

[1] Populations estimates with same letters after them within a temporal series not significantly different

My interpretation of the data contained in this report is that much of the difference between surveys is a result of movement of animals, possibly between Moreton Bay and Hervey Bay (the nearest adjacent dugong habitat). What proportion of these changes is attributable to movements is, at present, impossible to say. Proper assessment of this phenomenon in Moreton Bay specifically must be made in the context of aerial survey methodology that is consistent for longer periods as well as data on mortality rates, movements (via tracking and tagging, such as are occurring now in Hervey Bay and Moreton Bay respectively) and monitoring of the available seagrass resource (and other putative influences such as *Lyngbya*).

That dugongs migrate to Moreton Bay is not a new idea. As early as 1905 Thomas Welsby suggested that dugongs migrate from as far as Port Curtis and Bowen and noted that there were seasons in which dugongs were more abundant (Welsby 1905). More recently immigration into Moreton Bay from the north has been invoked as a potential explanation for other increases in the dugong population (Preen and Marsh 1995, Lanyon and Morrice 1997). Genetic evidence also supports such movements, with the haplotoype of a dugong from Moreton Bay being grouped with samples coming from as far afield as Shark Bay, Western Australia (Brenda McDonald *personal communication*). More generally, numerous genetic samples from Moreton Bay dugongs show no evidence of it being a population separate from the remainder of the east coast population, suggesting considerable interchange of individuals. There is less direct evidence available as yet for dugongs moving northwards out of Moreton Bay but I suspect that this reflects the lack of research effort rather than the absence of the phenomenon.

Sighting conditions

There is some potential for the estimate from the December 2000 survey to be an underestimate because cloud cover may have decreased visibility of dugongs at times during the survey. However, the areas surveyed under these conditions were those in which very few dugongs have been seen on previous surveys (Lanyon and Morrice 1997). I chose to survey under marginal conditions because of the different constraints of this, the first of three surveys. The major goal of this survey was to establish the pattern of dugong distribution in the bay before the expected *Lyngbya* outbreak in December 2000/January 2001. Thus it was imperative that a complete survey of the bay was done at this time and there was little opportunity to re-schedule the exercise appropriately due to continuing forecasts for similar weather.

I am confident that the December 2000 estimate is accurate for block 4 where the majority of dugongs were seen. Over both days, dugongs could easily be seen on the bottom over the sand banks. In anticipation of the development of new correction factors incorporating information on diving behaviour and visibility (Pollock, Marsh, Lawler *unpublished*), I recorded the water conditions for every dugong sighting. The categories used were: 1. substrate clearly visible and detail apparent, 2. substrate visible but detail not clear, 3. deep, clear water with high visibility and bottom not visible, 4. turbid water with low visibility and bottom not visible. In December 2000 92% of sightings were in the first two categories, thus it is unlikely that sufficient numbers of dugongs were missed to account for the difference between this estimate and the estimates made in 1995 (Lanyon and Morrice 1997).

In addition, in December 2000, Block 4 was surveyed twice. One was flown on December 12th with two observers and there was no cloud. The other was flown on December 13th with four observers and had cloud cover up to 6 oktas. The December 12th survey thus acts as a control for the effect of cloud on the December 13th survey. The dugong population estimates are the same (344±68 vs 344±88).

Similarly, there were times during the April 2001 survey when cloud cover was quite high. However, over Block 4, which is the crucial area, conditions were acceptable. During this survey, cloud cover was zero for transects 15-29 (except for 2 oktas recorded at the eastern end of transects 15 and 16). For transects 30-34 cloud cover was zero at the western end and up to 4 at the eastern end. Only on transect 5 was cloud cover recorded at 5 oktas (at the eastern end). The great majority of dugongs were seen between transects 22 and 31. I have no doubt that conditions were sufficient to see dugongs over this block. This is further supported by the fact that, in April 2001, 95% of dugong sightings were classified as being where the bottom could be seen, 78% where the detail could be seen clearly.

Differences in methodology

The surveys reported here followed the same transect design and general approach of Lanyon and Morrice (1997). The fundamental difference in the two methodologies was the height at which the aircraft was flown. Lanyon and Morrice (1997) surveyed at 275m (900 feet) while I surveyed at 137m (450 feet).

A survey height of 137m has been used in surveys of most of the coastline of northern Australia, including Shark Bay WA, the Gulf of Carpentaria, Torres Strait and the east coast of Queensland (Marsh 1986, Bayliss and Freeland 1989, Marsh and Saafeld 1989, 1990, Preen et al. 1995b, Marsh and Corkeron 1996, Marsh et al. 1996, Marsh et al. 1997, Preen et al. 1997, Marsh et al. 1998, Prince et al. 2001). Using a standardised survey height allows the estimates from Moreton Bay to be compared more directly to estimates of adjacent areas, and information on the movements of dugongs indicates that this is a critical aspect of data collection (the importance of which has been outlined above).

So the question that must be asked is: Is an aerial survey estimate of dugong population made by flying at an altitude of 137m inherently any better or worse than one flown at 275m? In fact, this has been tested explicitly in Moreton Bay itself (Marsh and Sinclair 1989b) and it was shown that the density of dugongs was not different between the two altitudes. Bayliss (1986) found animal densities to be higher at the lower altitude, but this was due to higher densities of turtles recorded at 137m, a result confirmed by Marsh and Sinclair (1989a). Therefore, it ought to be possible to compare the estimates made here to those of Lanyon and Morrice (1997). However, the very close spacing (1 km apart) of transects in the design used by both studies renders the comparison invalid.

In Block 4 of Moreton Bay, at the altitude flown by Lanyon and Morrice (1997), the transect spacing used is too narrow, such that there is a very high probability of double-counting of dugongs on adjacent transects. My estimates made from measurements on the ground indicate that at 275m altitude the distance under the plane between transects is well in excess of 200m. If this is added to the 400m transect width on each side of the aircraft the total survey width exceeds one kilometre. Assuming that the aircraft stays exactly on line (which it rarely does in practice), with the current spacing of transects at one kilometre apart (as per Lanyon and Morrice (1997)) there is a very high probability of overlap and thus overestimation of the population if the survey is conducted at 275m altitude. Note also that this error also leads to an overestimation of the survey intensity and population variance at the higher altitude

Relationship between dugong population estimates in Moreton Bay and Hervey Bay

Hervey Bay is the nearest area of substantial dugong habitat north of Moreton Bay (there are none to the south). It is approximately 130km from Moreton Bay, a distance that is clearly within the capacity of dugongs to traverse. Little is known of movements between these two bays specifically, but there are indications that it has at least occurred in the past. Following the loss of large amounts of seagrass in Hervey Bay in 1992 because of large scale flooding, the population of dugongs in Moreton Bay was estimated to have increased by 100-200 individuals, and this was interpreted as dugongs having migrated from Moreton Bay to Hervey Bay (Preen and Marsh 1995). This was also invoked as a potential explanation for the increase in dugong numbers recorded in the surveys of Lanyon and Morrice (1997).

In this context it is appropriate to consider the population estimates made via aerial survey for each of these bays and their relative timing. As noted above, Hervey Bay was surveyed using the current methodology in 1988, 1992 and 1993 (Preen 1995, Preen and Marsh 1995, Marsh et al. 1996, Lawler and Marsh 2000). At that time the population decreased by some 1600 animals and it was suggested that some of the dugongs had moved to Moreton Bay (a few individuals moved even greater distances, mortality of emaciated dugongs found near Sydney and north to Shoalwater Bay being attributed to the seagrass loss in Hervey Bay) (Preen and Marsh 1995). In 1994 Hervey Bay was again surveyed and the population had risen slightly to 807($\pm$151)(Marsh et al. 1996).

The Lanyon and Morrice (1997) estimates of the dugong population in Moreton Bay began two months after the 1994 Hervey Bay survey. This may appear to leave little scope for movement of a substantial portion of the population between the two bays, unless the movements are coordinated between individuals. It is possible, but unlikely, that if responding to a particular event (such as the seagrass loss described above for Hervey Bay), a large proportion of the population could easily move between bays in such a time period (there are currently no indications that such an event occurred at that time). However, there is then a gap in the survey schedules of four years before Hervey Bay was surveyed again in 1999 and a further year before Moreton Bay was again surveyed. During this time the mean estimates for the two bays changed substantially in opposite directions.

The dugong population of Hervey Bay in 1999 was estimated at 1654 (±248), an increase (but not statistically significant) over the estimate for 1994 of 807(±151) (Lawler and Marsh 2000). During the period from January 1995 to December 2000, the dugong population estimate for Moreton Bay decreased from a high of 896 (±201) to 344(±88). If there was going to be a substantial movement of dugongs from Moreton Bay to Hervey Bay, it had probably already occurred, and been recorded within this series of surveys.

That even these large changes were not statistically significant must be emphasised, as it highlights an aspect of monitoring programmes that is too often not appreciated. The statistical power of monitoring programmes to detect changes becomes increasingly weak as the population becomes smaller (Gerrodette 1987, Taylor and Gerrodette 1993, Marsh 1995). That is, it is possible to detect relatively small proportional changes in a larger population (say, the dugong population of the Northern GBR) but at the population size of an individual bay such as Moreton Bay, changes must be proportionally very large before they can be shown statistically. In terms of the changes between 1995 and 2000 in Moreton Bay, the inability, for the reasons outlined earlier, to make formal statistical comparisons compounds the problem. The inclusion of Hervey Bay in the April and December 2001 surveys was only going to be able to demonstrate very dramatic changes in the population of either bay with any confidence. It should also be noted that changes could also be overlooked if animals moved north beyond Hervey Bay, as is well within their capacity.

As it happened, during this survey program, the estimated dugong populations of both Moreton and Hervey Bays appeared to increase between April and November 2001 and thus neither can easily be invoked as the source of immigrants for the other (nor was either statistically significant). In the case of Hervey Bay I suspect that the change in the population estimate is an artefact of a change in the distribution of dugongs in winter similar to that often remarked on for Moreton Bay (Preen 1993, Lanyon and Morrice 1997). That is, as water temperature cools with winter approaching Hervey Bay dugongs may move to deeper water areas to escape the cold. In deeper areas, because the dugongs spend proportionally less time at the surface, the current availability correction factors may not sufficiently account for those underwater at the time the aircraft passes overhead, thus leading to an underestimate of the population. This is the first time that Hervey Bay has been surveyed in April and thus there are few comparative data to assess this possibility. Current studies of the movements of Hervey Bay dugongs may give some insight into the situation (Sheppard, Lawler, Marsh *unpublished*). The ongoing development of new correction factors for these surveys (Pollock, Marsh, Lawler *unpublished*) may alleviate these problems in future.

Aerial surveys are certainly valuable in determining large-scale distribution and abundance of dugongs. However, management of dugongs at smaller scales also requires information on other aspects of their ecology to enable interpretation of survey results, particularly where the statistical power to detect population trends is low. Data on dugongs movements and what stimulates them, and monitoring of the seagrass resources on which they depend should be the minimum sought in these instances.

Effects of **Lyngbya** ***on dugongs in Moreton Bay***

The data contained in this study provide little evidence of any effect of *Lyngbya* on the dugong population of Moreton Bay. In fact the mean population estimate increased during the course of the study (but this wasn’t statistically significant). However, this should not be taken to indicate that there is no effect of *Lyngbya*, or no potential for effects in the future.

As described in the introduction, it was fortunate that there was no outbreak of *Lyngbya* on the Moreton and Amity Banks in 2001 on the scale that occurred in 2000. However, there were at times low concentrations of *Lyngbya* on the banks distributed such that it may be suspected to have had some effect. Dugongs feed preferentially over those areas of the bank where the seagrasses *Halophila ovalis* and *Halodule uninervis* predominate (Preen 1993). In these areas seagrass cover is low and patchy. During 2001 (the period of this study), *Lyngbya* was present in low concentrations but it tended to be growing anchored to the seagrass, thus maximising the potential for dugongs and green turtles to be exposed to the toxic effects of *Lyngbya* (C. Limpus *personal communication*). It's *effective* distribution was therefore much higher than a simple measure of percentage cover would tend to indicate.

Despite this, there was no change in the distribution of dugongs that would indicate an avoidance response to the *Lyngbya*. There was some tendency for dugongs to concentrate around the Rous Channel in the April survey, but this is consistent with seasonal movements as recorded in earlier studies (Preen 1993, Lanyon and Morrice 1997). It should be noted, however, that aerial surveys give only very coarse spatial information. Wholesale movements of the majority of individuals to different areas may be detectable, but it is not possible to discern changes at the level of individual patches of seagrass.

At this stage there is little to suggest that the dugongs in Moreton Bay have been significantly affected by the presence of *Lyngbya*. There has been no evidence collected to show that dugongs ingest *Lyngbya* incidental to feeding on seagrass nor has *Lyngbya* been implicated in the death of any dugong in Moreton Bay (C. Limpus *personal communication*). However, this may be more a reflection of the small number of samples examined to date. Is it known the manatees in Florida consume *Lyngbya* apparently without ill effect (J. Reynolds *personal communication*), however, there is considerable variation within the single species *L. majuscula* in the types and amounts of toxins produced (Osborne et al. 2001). Such variation has been found to occur at different times over the banks where dugongs congregate in Moreton Bay (C. Limpus *personal communication*). Overall, given the well known effects that *Lyngbya* has, at times, on other mammals, the scale of the 2000 outbreak and our limited understanding of how and why the toxicity of *Lyngbya* varies, the potential for *Lyngbya* to negatively impact dugongs in Moreton Bay remains a concern and should be the focus of ongoing research.

Aerial survey should be only one aspect of a multifaceted approach to the issue of how *Lyngbya* will affect the dugong population in Moreton Bay. As noted above, aerial survey provides coarse spatial information. Its use is also only amenable to reactive management. That is, it cannot be used to predict upcoming events, but rather it enables the scale of a past event to be assessed. Future research on this issue would more appropriately be directed at more detailed examination of dugong carcasses to determine causes of death of Moreton Bay dugongs, examination of stomach contents of dugong carcasses to determine whether *Lyngbya* is indeed ingested and perhaps pathological studies to determine whether dugongs absorb *Lyngbya* toxins and what effects this might have. This would give a more thorough understanding of the system and may enable the significance of events to be assessed in advance. Similarly, continued monitoring of *Lyngbya* occurrence and the ecological cues leading to outbreaks will be valuable. Current research on the dugong ecology being undertaken in Moreton Bay and Hervey Bay may also contribute to a clearer picture of the situation.

Turtles and cetaceans

Turtles were widely distributed throughout Moreton Bay on all surveys, but with clearly higher concentrations over the eastern banks areas, broadly similar to the distribution of seagrasses in the area. In each case the estimated population of turtles was in excess of 1000 individuals. However, as noted previously, there are numerous difficulties in estimating turtle populations via aerial survey. These include their very variable diving behaviour, difficulty in identifying turtles to species level and the unknown proportion of juvenile individuals that are unable to be identified. Consequently these estimates should be regarded as potentially substantial underestimates of the true turtle population for Moreton Bay. They are provided simply for comparison with previous estimates (Lanyon and Morrice 1997) although such comparisons should be cautious due to the greater ability to distinguish small individual turtles at the altitude used in this study (Marsh and Sinclair 1989b). The value of these data lie more in the recording of the distribution of turtles. As discussed previously for dugongs, distributional data are coarse scale and may be useful to indicate wholesale shifts of habitat use by the turtles, such as may be expected in response to *Lyngbya* outbreaks. There is little here to indicate any such change, but the caveats in regard to species identification and small individuals apply also to this interpretation. I have not attempted any further consideration of the effect of *Lyngbya* on turtles in Moreton Bay as I understand this to be currently under investigation by Dr Col Limpus and co-workers, who are far more expert in the area.

In Hervey Bay the distribution of turtles was throughout the Great Sandy Straits extending into the southern bay and along it's western shoreline again being approximately coincident with seagrasses in the region. No attempts were made to estimate the population, for the reasons outlined above.

The data collected on cetaceans in these surveys do not add greatly to our understanding of these species in the bays. These aerial surveys are designed as dedicated dugong surveys and are not appropriate for population estimation for dolphins. This is most clearly shown by comparison of the numbers of dolphins seen relative to populations estimated made by other means. The two main species of dolphin in the bay are *Tursiops aduncus* and *Sousa chinensis*. The most recent estimates for the two in Moreton Bay are: *Tursiops* 818 ± 152 s.e. (Chilvers 2001), and; *Sousa* 119 (95% CI=81-166) (Corkeron et al. 1997). These sum to close to 1000 animals, while the largest number of animals seen in Moreton Bay was 48 animals (in 27 groups). Thus aerial survey estimates would substantially underestimate dolphin population size without appropriate correction factors (for which there are no data available for calculation). Data on cetaceans collected during dedicated aerial surveys for dugongs should be continue to be collected, in case some unusual event is recorded (for example the occurrence of a rare or unusual species, such as irrawaddy dolphins) but are unlikely to be useful for monitoring populations of the two common species.

Conclusions and recommendations

In conclusion, the series of aerial surveys conducted in this study have recorded estimates of dugong population size of Moreton Bay ranging from 344 (±88) to 493 (±45). The preliminary results in particular raised concerns about a decline in the Moreton Bay dugong population. Problems of differing methodologies and low statistical power, preclude any firm conclusions on the topic. Such findings must be interpreted in the context of all other available information, such as the state of the food resource, levels of mortality in the dugong population and other potential impacts, such as *Lyngbya*. At present there is little such information to raise concern. Similarly, in light of the history of variable population estimates for Moreton Bay and the increasing understanding of the frequency and scale of dugong movements, the revised population estimate for Moreton Bay should not yet been considered to be indicative of a major problem.

The estimates of the dugong population size for Hervey Bay are more easily interpretable and are consistent with earlier surveys. Population size appears to have recovered and begun to stabilise in Hervey Bay following the catastrophic loss of seagrass in 1992. At present the dugong population of Hervey Bay appears secure, but it remains vulnerable to similar losses in future if flooding on that scale recurs.

Although I have noted that these results do not raise immediate concerns for the conservation of the dugong population of Moreton Bay, it is a substantial population and is the only such population adjacent to a major metropolitan centre. Consequently, the dugongs of Moreton Bay are faced by a number of threats or potential threats that include, but are not limited to, further outbreaks of *Lyngbya*, increasing boat traffic and a proposed aquaculture facility in an adjacent area. For these reasons monitoring of the Moreton Bay dugong population should continue but should not be confined to aerial survey.

At a minimum, ongoing research should include:

- Monitoring of the seagrass resource available to dugongs.
- Monitoring of the distribution and abundance of *Lyngbya*.
    - This should include further investigation into the toxins occurring in *Lyngbya*, the factors that cause them to vary, and their toxicity to dugongs and other significant fauna.

- Aerial surveys to continue but methodology and timing to be standardised and coordinated with future surveys of adjacent Hervey Bay and the Great Barrier Reef Marine Park (in collaboration with the agencies responsible for managing dugong populations in each of those areas).

Currently there are ongoing investigations of dugong ecology in both Moreton Bay and Hervey Bay. My understanding is that the Moreton Bay study (run by Dr Janet Lanyon of University of Queensland) is examining population size and life-history parameters via individual tagging of dugongs with long term markers and mark-recapture style studies. In Hervey Bay the focus of the study (run by myself, Prof Helene Marsh and Mr James Sheppard, all of JCU) is examination of movements using GPS-based technology, in addition to a study of variability in nutritional quality of the seagrass resource for dugongs (the PhD project of Juanita Bité, JCU). It is to be hoped that these studies will provide data on the movements of animals between the two bays (and beyond) that will go some way to resolving the current difficulties in interpreting the time series of aerial survey estimates to date.

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(Bayliss 1986)

Source
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This study