

An Experimental Evaluation of Dugong and Sea Turtle Aerial Survey Techniques

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Abstract

Some factors which affect the aerial counts of dugongs and sea turtles were examined experimentally. There was no significant difference in the observed density of dugongs when survey height was doubled from 137 m to 274 m with an accompanying doubling of transect width on either side of the aircraft from 200 m to 400 m. In contrast, a significantly higher density of turtles was observed at the lower height/narrower transect width. The higher level of glare on the exposed side of the aircraft, the time of day and the time from high tide made no significant difference to the observed densities of dugongs or turtles. The survey crew included a tandem team of two observers on each side of the aircraft, who reported their uncolluded observations into separate tracks of a two-track tape recording system. This allowed the reports of tandem observers to be compared in order to assess observer reliability. Overall, observers missed over 40% of dugong groups and over 80% of turtles visible within the transect including groups of more than 10 dugongs. The chance of observers missing a group of dugongs was independent of group size. There was little disagreement between tandem observers about the identification of animals, or the position of animals in the water column. However, observers differed markedly in their categorisation of dugong behaviour and in their counts of animals (particularly dugong calves) in larger groups.

Introduction

The range of the dugong (*Dugong dugon*) in Australia extends along about 15 000 km of coastline and over 58 km from the coast in some areas. Aerial survey is the only feasible method of taking a census of dugongs over such remote and extensive areas. However, the technique is inaccurate and often provides gross underestimates of animal numbers (Caughley *et al.* 1976). Consequently, Caughley (1979) has argued that aerial survey estimates are probably most useful as indices for tracking relative density over time. For this purpose, an important requirement is that survey procedures be rigidly standardised.

Aerial survey procedures for dugongs are still being developed. Early surveys (e.g. Heinsohn *et al.* 1976; Anderson and Birtles 1978; Brownell *et al.* 1981; Elliott 1981; Marsh *et al.* 1981; Prince *et al.* 1981; Anderson 1982) were essentially qualitative, their main use being to identify areas of relatively high dugong density.

Because of the extensive distribution of dugongs in Australia, the first two quantitative surveys (Bayliss 1986; Marsh 1986) used a strip transect technique, developed by Caughley and Grigg (1981) to survey kangaroos in the outback. However, there were differences in the procedures used in the dugong surveys. Marsh (1986) surveyed at 274 m (900 feet) with a transect width of 400 m on each side of the aircraft. Bayliss (1986) flew at 137 m (450 feet), with a transect width of 200 m on each side of the aircraft, on the basis of a

preliminary experiment which showed that the observed density of animals (based on the combined sightings of dugongs, dolphins and sea turtles) was significantly greater with the 137/200 m survey regime than with the 274/400 m regime. Flying at the lower height/narrower transect width doubles the survey time needed to achieve the same sampling fraction. This cost differential is substantial, given the vast areas to be covered and the high sampling intensity required to achieve a useful index of density. [The population estimates of both Bayliss and Marsh had a precision (s.e./m. %) of about 18% at a survey intensity of about 7%.]

In this paper, the effect of survey height/transect width on the sightability of dugongs has been re-examined in an experiment which also tested the effects of glare off the surface of the sea, time of day, and tidal cycle on observed dugong density. Other large marine vertebrates were also counted during the experiment, allowing parallel questions to be addressed with respect to sea turtles (probably green turtles, *Chelonia mydas*).

The survey crew included a tandem team of two observers on each side of the aircraft, who reported their uncolluded observations into separate tracks of a two-track tape recording system. This allowed the reports of tandem observers to be compared in order to assess observer reliability.

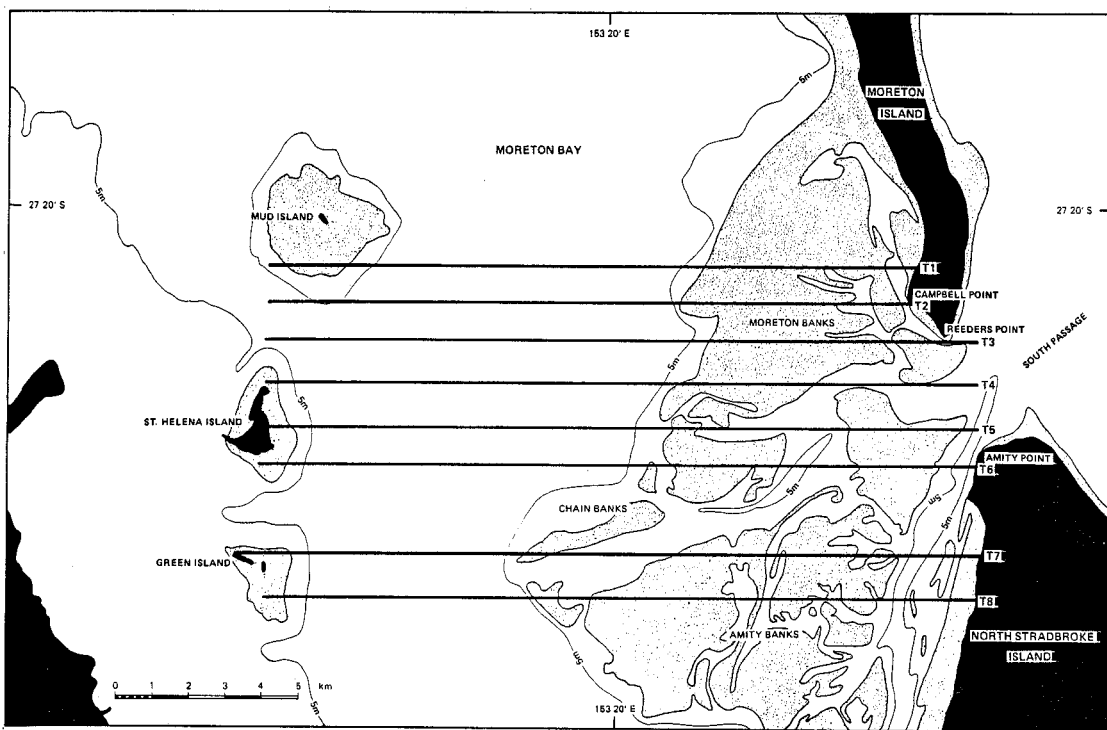


Fig. 1. Map of the survey area in Moreton Bay showing the locations of the aerial survey transects.

Materials and Methods

Design

The experiment involved flying eight transects over a small part of Moreton Bay (Fig. 1) twice daily within 3 h of high tide at the Brisbane Bar on 2 and 5–8 June 1985. Plans to run the experiment over five successive days were abandoned because of unsuitable weather on 3 and 4 June. To aid navigation, eight east-west transects were selected *a priori* on the basis of clearly defined end-points in an area of known high dugong density (Fig. 1). The transects ranged in length from 21.2 km to 25.1 km.

Five daily flight plans were drawn up in advance, and flown in random order. Each plan was defined by the following variables which were selected using random number tables.

- (1) Starting transect (T1, T2, T3, T4, T5, T6, T7 or T8).

- (2) Direction of travel for the starting transect (west or east), which defined the direction of travel for all subsequent transects, as each transect after the first was flown in the opposite direction to its predecessor.
- (3) Direction of movement between successive (adjacent) transects (north or south).
- (4) Height at which each transect was to be flown initially (137 or 274 m). The second time, each transect was flown at the alternative height and in the opposite direction.

Thus each transect was flown at each height on each day, once in an easterly and once in a westerly direction. Direction of the aircraft determined the level of the factor glare on each side of the aircraft. Operational constraints necessitated confounding height and glare.

Survey Techniques

All transects were flown at a ground speed of 185 km h^{-1} (100 knots), the slowest speed the aircraft (a Partenavia 68B) could safely maintain within the range of acceptable wind conditions.

The survey team comprised a commercial pilot with previous dugong survey experience, a front-right survey leader, two mid-seat observers, and two rear-seat observers (see fig. 1 in Marsh and Sinclair 1989). All team members occupied the same seats throughout the experiment. The middle and rear seat observers on the same side of the aircraft formed a tandem team searching the same transect. All observers had experience with dugong surveys on which turtles and dolphins were also reported. The two rear-seat observers had acted as observers on a quantitative dugong survey less than two months previously. In contrast, the two mid-seat observers had been involved in qualitative surveys only.

Transect width, demarcated by fibreglass rods attached to artificial wing-struts, was 200 m on either side of the aircraft at the survey height of 137 m and 400 m at 274 m. The rods were positioned specifically for each rear-seat observer and checked empirically prior to the survey as outlined by Norton-Griffiths (1978). During this check, it was also confirmed that the transect width scanned by both the observers in a tandem team was similar. Tape was placed on the windows of the aircraft to ensure that each observer's head was kept in the correct position during flight (see Norton-Griffiths 1978). Within the constraints imposed by these marks, observers adjusted their viewing angles to minimise the effect of glare. All crew members wore identical polarized sunglasses.

Data were recorded by the survey leader, using an Epson HX20 portable microcomputer programmed as a data-logger and timer, and equipped with a printer that produced an immediate hard copy of the data. The time of entry for each observation was recorded automatically, enabling its position to be plotted on a map later for habitat analysis.

The survey leader was responsible for keeping a regular check on aircraft speed and altitude (measured by pressure altimeter), and for recording details of weather condition, including wind speed and direction, cloud cover (oktas), the nature of the sea surface (Beaufort scale), the times at which each transect began and ended, and the observations of the rear-seat observers, including the relative amounts of glare off the surface of the water on either side of the aircraft. The start and end of each transect were announced by a whistle blown by the pilot.

The rear-seat observers communicated with the survey leader via a two-way intercom system connected to one track of a two-track tape recorder. They reported the following information in standardised format at the time of first sighting.

- (1) Dugongs: group size, number of calves, behaviour (swimming, idling, feeding diving), number at the surface.
- (2) Turtles: group size, position in the water column (surface or underneath).
- (3) Dolphins: group size, number of calves, species, reliability of specific identification (certain, uncertain), position in the water column.
- (4) Incidental sightings of rays, sea snakes, sharks, surface plankton.

During the transects, the mid-seat observers were visually screened from the rear-seat observers with a curtain, and acoustically isolated from the other crew (apart from each other). They reported their sightings in the standard format into the second track of the tape recorder. Between transects, the intercom channels were switched so that all members of the crew could communicate. The surveys were conducted between 0830 and 1300 h. A maximum of 3.2 h (2.5 h survey time) was spent in the air at one time.

Post-survey Data Review

The tape record of each transect was used to check and edit the computer records, so that each sighting could be coded as being made by one (specified) member or both members of a tandem observing team. The reports of team members were deemed to be different if they were unambiguously distinct (usual situation) or if they were separated by approximately 5 s or more. Discrepancies between dual sightings of the same group were also noted.

Analysis

(i) Analysis of variance

Analysis of variance was used to determine the effect of the various survey variables (survey height/transect width; tandem observing team; glare) on the density of dugong and turtle sightings. Day and transect were treated as random effects. As the factor glare was not orthogonal to survey height/transect width and tandem observing team, the effect of glare was analysed separately at each level of survey height/transect width. The possible effects of time of day and tidal cycle were investigated, using analysis of covariance. Input data were the densities of dugongs and turtles observed by each tandem team on each transect, at each survey height/transect width on each day. The densities were log-transformed for analysis to equalise the error variances.

(ii) Log-linear models

The counts of dugong groups were cross-classified in a number of 3-way arrays. These contingency tables were analysed using log-linear models (Fienberg 1980) to test various hypotheses concerning factors which could affect sightings. A standard hierarchical model-fitting procedure was adopted, with only significant effects being retained in the model. The absence in the final model of an interaction term between a pair of factors indicated that those factors were acting independently. The goodness-of-fit of a model was gauged by the log-likelihood χ^2 value.

The *G* statistic used in the analysis of other results, as indicated in the text, was calculated using Williams' correction (Sokal and Rohlf 1981).

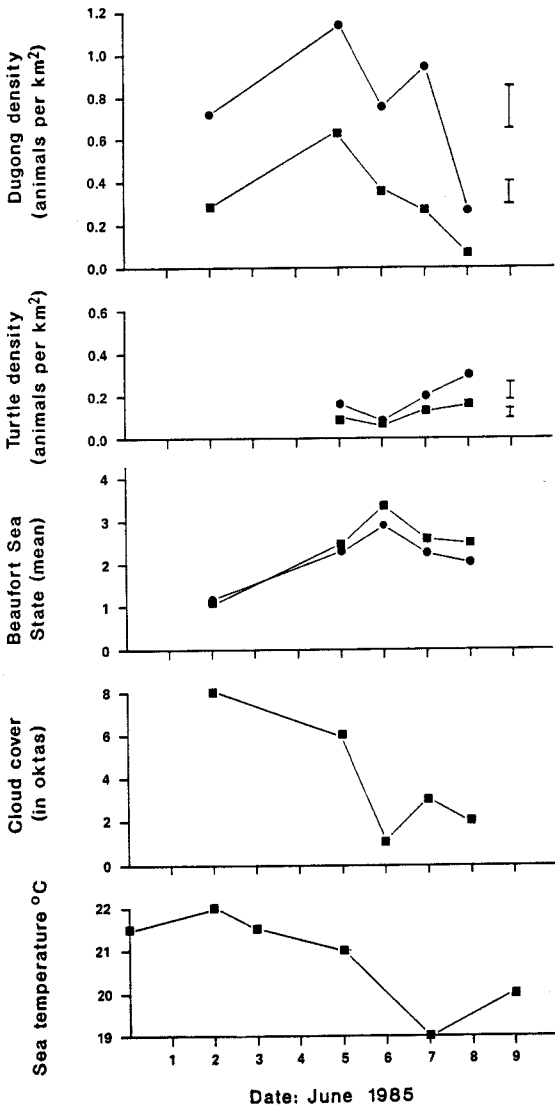


Fig. 2. Changes in the mean daily observed density of dugongs and turtles in relation to the weather conditions. The sea surface temperatures were measured at Point Lookout on the ocean side of North Stradbroke Island by the shark meshing contractor employed by the Queensland Department of Harbours and Marine. The limited data available suggest that the corresponding temperatures in the survey area would have been at least 3°C colder. ■ mean densities of dugongs or turtles calculated over the full transects, ● mean densities of dugongs or turtles calculated over the sandbank area only. Range bars indicate the pooled s.e.s from the analysis of variance.

Results

Summary of Sightings

In all, 341 groups of dugongs, 206 groups of turtles and 15 groups of dolphins were sighted during the experiment. The daily cloud and sea conditions encountered are summarised in Fig. 2.

(i) *Dugongs*

A group of dugongs was defined as a subjectively distinct clump. The frequency distribution of dugong group sizes is summarised in Fig. 3. Group size ranged from one to 20 with a mean of $2.08 \pm \text{s.e. } 0.139$ dugongs. Large groups were relatively rare; 61.6% of groups consisted of a single animal, 83% consisted of a single animal or a cow-calf pair. All but 15 dugong groups (4.4%) were sighted on the shallow sandbank area west of South Passage bounded by the 5-m depth contour line (Fig. 1).

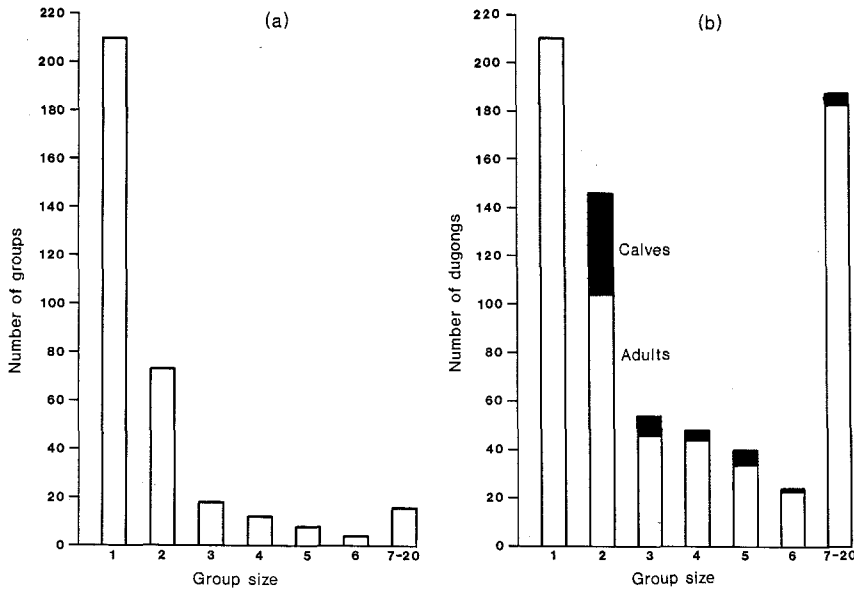


Fig. 3. (a) Frequency distribution of group sizes of dugongs; and (b) number of dugongs in groups of various sizes and the corresponding calf counts. The calf counts are likely to be negatively biased (see text).

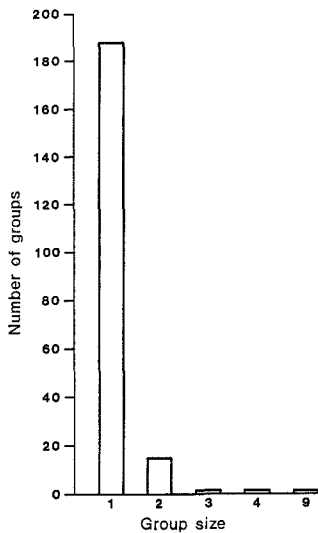


Fig. 4. Frequency distribution of group sizes of turtles. A group tended to represent a number of animals seen in rapid succession rather than a cohesive entity.

(ii) *Turtles*

It is usually much more difficult to define a group of turtles than a group of dugongs, and group sizes of more than one typically represent turtles seen in quick succession rather than a cohesive group. The frequency distribution of turtle group sizes is summarised in Fig. 4. The largest group comprised nine turtles; the mean group size was 1.14. We were unable to confirm the specific identification of the turtles, although they were almost certainly *Chelonia mydas* (C. J. Limpus, personal communication). Twenty-five per cent of turtle groups were seen away from the sandbanks west of South Passage, a significantly larger proportion than for dugongs ($G=39.96$, 1 d.f., $P<0.001$).

Table 1. Mean densities of sightings (animals per km²) for each survey height/transect width, tandem observing team and direction of the sun on observers

The *F*-value, degrees of freedom and probability are shown for each main effect. There were no significant interactions

	Dugongs		Turtles	
	Full transects	Banks only	Full transects	Banks only
Survey height/transect width ^A				
137 m/200 m	0.296	0.772	0.173	0.290
274 m/400 m	0.348	0.754	0.054	0.081
	$F=1.275$	$F=0.479$	$F=16.123$	$F=10.102$
	1,35 d.f.	1,35 d.f.	1,28 d.f.	1,28 d.f.
	$P>0.25$	$P>0.25$	$P<0.0005$	$P<0.005$
Tandem observing team ^A				
Port	0.0337	0.879	0.167	0.278
Starboard	0.0307	0.646	0.060	0.092
	$F=2.712$	$F=3.06$	$F=29.971$	$F=28.6$
	1,35 d.f.	1,35 d.f.	1,28 d.f.	1,28 d.f.
	$P>0.10$	$P>0.05$	$P<0.0005$	$P<0.0005$
Aircraft direction ^B				
Lower glare (south side)	0.418	0.879	0.111	0.153
Higher glare (north side)	0.422	1.005	0.084	0.142
	$F=0.231$	$F=0.063$	$F=1.819$	$F=0.054$
	1,21 d.f.	1,21 d.f.	1,21 d.f.	1,21 d.f.
	$P>0.25$	$P>0.25$	$P>0.10$	$P>0.25$

^A Mean of days 1-5 for dugongs, 2-5 for turtles.

^B Mean of days 2-4.

Effects of Survey Variables

The results of the analyses of variance examining the effects of the three survey variables (survey height/transect width referred to as survey regime, tandem observing team, and glare) on the observed densities of dugongs and turtles are given in Table 1. The day 1 turtle sightings were excluded because the two mid-seat observers included 'possible turtles' in their counts; more rigorous standards were applied on the other days. Glare was always higher on the north side of the aircraft on days 2-4, but inconsistent on days 1 and 5. Consequently, results from the latter days were also excluded from the analysis of the effect of glare.

None of the three survey variables had a significant effect on observed dugong density. However, for turtles, a significantly higher density was recorded at the 137/200 m survey regime, and the two tandem teams differed significantly in their observed densities. The differences were large both on and off the sand bank area, and were consistent for both survey regimes.

Glare had no effect on either dugong or turtle counts and inclusion of time from dawn and time from high tide as covariates did not alter the results.

There were no significant differences in observed turtle density ($P > 0.05$) between days 2-5. For dugongs, however, the differences in daily sightings were significantly different ($P < 0.05$), day 2 being significantly higher and day 5 significantly lower than the other days (Fig. 2).

The differences between days in the observed density of turtles, both on the banks and over the full transects, were not statistically significant (Fig. 2). However, they do coincide with the corresponding changes in sea state; fewer turtles were seen in rougher seas (Fig. 2). In contrast, the significant differences between days in observed dugong density show a pattern that does not coincide with changes in sea state and cloud cover (Fig. 2). A large aggregation of dugongs was observed adjacent to the survey area on the seaward side of South Passage on day 5, suggesting that at least some of the observed difference in dugong density between days was due to animals moving from the survey area.

Comparison of Tandem Observers

Of the animals sighted during the experiment, 57% of the dugong groups and 18% of the turtle groups were seen by both members of either team of tandem observers. This allowed the observations of tandem team members to be compared directly as follows.

(i) *Species identification*

Tandem observers differed on, at most, seven occasions (3% of the number of dual sightings of all animals); three at a height of 137 m, four at 274 m. On two occasions, one observer classified an animal as a dugong when the counterpart was unsure. A further two animals classified as dugongs by one observer, were apparently classified as a turtle and a

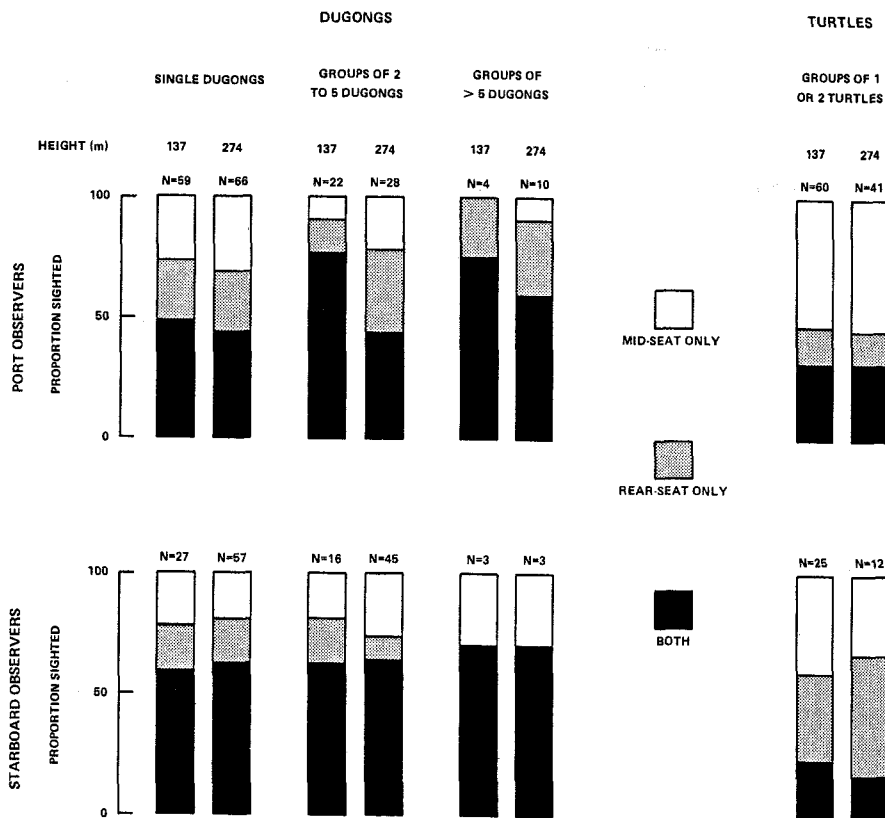


Fig. 5. Proportion of dugong and turtle groups sighted by the mid-seat observer, the rear-seat observer or both observers in each tandem team. The data are presented separately for each survey regime, and for dugong groups in different size categories.

dolphin by the other. Other disagreements over identification were one turtle/ray, a group of dolphins/fish and a dolphin/shark.

(ii) *Dugongs*

The proportion of groups sighted by one or both observers in the port and starboard teams at each survey regime is summarised in Fig. 5, which shows that all observers missed a substantial proportion of dugong groups. The log-linear model relating frequency of sightings to sighting class (mid-seat observer only, rear-seat observer only, or both observers), survey regime (137/200 m, 274/400 m) and estimated group size (1, 1-5, >5), contained no interaction terms. Thus, the chance of an observer missing a group of between 6 and 20 dugongs was not significantly different from the chance of missing a smaller group at either survey regime (port team: $\chi^2 = 12.19$; d.f. = 12; $P = 0.43$; starboard team: $\chi^2 = 4.58$; d.f. = 12; $P = 0.97$). Three of the four observers missed a group of 10 or more dugongs (one occasion each).

Group size. The estimate of group size differed in 21 (11%) of the 193 groups sighted by both members of a tandem observing team. Discrepancies were significantly more likely for groups of more than five dugongs than for smaller groups ($G = 26.516$, d.f. = 1; $P < 0.001$). The tandem observers obtained the same count for only six of the 16 groups of more than five dugongs. The greatest discrepancy was between corresponding group size estimates of 14 and 19 dugongs; in most instances the discrepancy was one or two. On four occasions, the difference occurred because one of the tandem observers failed to see a calf.

When members of a tandem team disagreed about group size, the lower count was arbitrarily used in all analyses, including the estimate of mean group size (2.08). If the estimates of the rear-seat observers only had been used, the mean group size would have been 2.12. The corresponding figure for the two mid-seat observers was very similar (2.14).

The proportion of groups in which the size estimates of both tandem observers were identical, was consistent over survey regimes and observer teams ($\chi^2 = 1.92$; d.f. = 3; $P = 0.59$). All observers reported insufficient time to count calves in large groups, and the proportion of calves counted in groups of five or more dugongs (Fig. 3b) was significantly lower than that in groups of two to four dugongs ($G = 33.5$; d.f. = 1; $P < 0.001$). There is no evidence to suggest that the relative frequency of calves should be less in large groups of dugongs than in smaller groups.

Behaviour. The two members of a tandem observing team differed in their categorisation of the behaviour of 43 (22%) of the 193 groups sighted by both of them. However, the proportion of behaviours classified similarly by both members of a tandem team did not vary significantly with survey regime ($\chi^2 = 3.32$; d.f. = 2; $P = 0.19$).

These results indicate that observers cannot reliably classify dugong behaviour into even simple categories in the time available, at least without further training.

Number of dugongs at the surface. There were 172 groups for which both members of a tandem observing team counted the same number of dugongs. The tandem observers differed in their assessment of the number of dugongs at the surface in only nine of these (5%). This proportion did not vary significantly with survey regime and observer team ($\chi^2 = 2.49$; d.f. = 3; $P = 0.49$).

Individual dugongs were often seen in the process of surfacing or diving while an observer scanned the surface of the sea; therefore some dugongs will be seen at different stages of this behaviour by different observers. Under these circumstances, the 5% disagreement over the position of dugongs in the water column is not surprising. The position of a dugong in the water column can thus be assessed reliably using either survey regime.

The bottom of the bay was clearly visible when flying over the sandbanks, and so it was theoretically possible to see all dugongs present. In contrast, the bottom was not usually visible during the remainder of the transects that were over deeper water, and not all the dugongs below the surface would have been visible. The proportion of the dugongs sighted that were classified as being on the surface varied from 18/37 (48.6%) off the banks, to

91/673 (13.5%) on the banks. The difference is significant ($G=20.45$; d.f. = 1; $P<0.001$), and forms the basis of the 'availability correction factor' developed by Marsh and Sinclair (1989).

On the sandbanks, the proportion of dugongs classified as being on the surface was significantly less for groups of more than five dugongs (11/193) than for smaller groups (80/480) ($G=16.219$; d.f. = 1; $P<0.001$), presumably because the observers did not have time to record accurately the proportion on the surface for the bigger groups. The proportion of dugongs in groups of five or less on the sandbanks that was recorded as being on the surface (80/480 or 16.7%), should be a reliable estimate of the proportion on the surface in this area at the time of the survey. This value is not significantly different from that obtained independently from vertical colour photographs of dugongs (68/486 or 14.0%), taken under excellent conditions on the same sandbanks in October 1984 and December 1985 ($G=1.33$; d.f. = 1; $P>0.10$).

(iii) Turtles

The number of groups in each sighting class (mid-seat observer only, rear-seat observer only, both observers) for the port and starboard teams at each survey regime is summarised in Fig. 5. The proportion of groups in each sighting class was independent of survey regime (port team: $G=2.74$; d.f. = 2; $P>0.10$; starboard team: $G=0.64$; d.f. = 2; $P>0.5$).

There were no discrepancies between the reports of tandem observers regarding the same group of turtles, apart from disagreement about whether or not two (separate) turtles were on the surface.

The proportion of turtles classified as being on the surface was independent of survey height/transect width ($G=1.32$; d.f. = 1; $P>0.10$). Overall, 38% (81/234) of turtles were classified as being on the surface. This is undoubtedly an overestimate. Many bottom-dwelling turtles were not recorded by observers because it was uncertain whether the animals were turtles or rays.

Discussion

Reliability of Observers

Analysis of variance indicated a significant difference between the tandem teams in the observed density of turtles (but not dugongs) at both survey regimes. This was due to the port mid-seat observer recording far more turtles than any of the others (Fig. 5), suggesting that training was inadequate for spotting turtles. It would be particularly valuable if such training also enabled observers to identify species of turtles from the air.

The two-track tape recorder allowed observer reliability to be assessed by comparing the dual sightings of tandem observers. There was little disagreement about species identification or the position of dugongs or turtles in the water column. However, the level of disagreement about the behaviour of dugongs (22% of dual sightings) was so high that we decided to discontinue collecting such data.

Observers had difficulties in recording data from dugongs in large groups. As a result, groups of more than 10 animals are now photographed. When a large group is encountered, the transect is discontinued at a convenient reference point in order to return to photograph the group (see Marsh and Saalfeld 1989), as suggested by Norton-Griffiths (1978). The transect is then resumed. Such groups are then 'stratified out' of the population estimate based on the transect count, and included in a separate 'strata of large herds' (Norton-Griffiths 1978).

We were surprised that the chance of an observer missing a group of dugongs was independent of group size, as this differs from the result obtained for some other species (Newsome *et al.* 1979; Samuel and Pollock 1981; Gasaway *et al.* 1985; Samuel *et al.* 1987). Our result is probably partially due to the relatively small range of group sizes encountered (Fig. 3), and the few groups with more than five dugongs. The failure of three of the four observers to see a group of more than 10 dugongs within the transect is unlikely to be due to edge effects, as subsequent experiments have shown that the visibility of dugongs is constant across the width of the transect (Marsh and Saalfeld, unpublished data). We

postulate that most large groups are missed when an observer interrupts the search pattern because the eyes linger on an animal in order to check its identification. Marsh and Sinclair (1989) outline methods for correcting for animals which are visible in the transect, but missed by observers.

Factors Affecting Visibility

On the basis of a preliminary experiment, Bayliss (1986) suggested that it is preferable to survey dugongs at an altitude of 137 m and a transect width of 200 m rather than an altitude of 274 m and a transect width of 400 m. However, although the combined doubling of survey altitude and transect width reduced the observed density of dugongs by 50%, the difference was not statistically significant because of the small sample sizes in Bayliss' study (see his fig. 2). Our results, based on a substantially larger sample size, indicate that there is no significant difference in observed dugong density between the two survey regimes. The experiment confirmed Bayliss' (1986) result that a significantly higher density of turtles is observed at the lower height/narrower transect width. If density estimates are required for both dugongs and turtles, it is clearly preferable to use the 137 m/200 m regime. However, if dugongs are the only species of interest, the same precision should be achieved by spacing the transects twice as far apart and surveying at the 274 m/400 m regime, although the associated distribution maps would be less detailed at the lower sampling intensity.

Two other factors need to be considered when deciding on the preferred regime. Caughley and Grigg (1981) point out that a large proportion of the hours in the air required to complete a survey are spent in relocating the aircraft, rather than in surveying, especially when operating in remote areas. Thus doubling the time spent in surveying will not necessarily double the cost of a survey. In addition, the actual numbers of dugongs seen per unit survey time is usually very low (see Bayliss 1986; Marsh 1986). As observers are much more alert and interested when they are actually recording sightings, it is advantageous to record other large vertebrates (mainly turtles) during a dugong survey. It is suggested therefore, that dugongs should be surveyed in conjunction with other large vertebrates, using the 137/200 m survey regime.

No difference was detected in the observed density of dugongs or turtles that could be attributed to the higher intensity of glare encountered on the north side of the aircraft on days 2-4. However, Marsh (1986) found that counts of dugongs were depressed on the glare side of the aircraft during an aerial survey in Torres Strait (10°S) in which the transects were aligned north-south rather than east-west as in this study. Holt and Cologne (1987) also found that glare depressed dolphin sightings. The effects of glare are very variable (unpublished data); they are probably best compensated for by careful consideration of how transects should be angled, supplying observers with polarised sunglasses, and using survey-specific correction factors to counter perception bias, i.e. animals that are visible in the transect and missed (see Marsh and Sinclair 1989).

Biological Insights

The low density of dugongs observed in the survey area on 8 June (Fig. 2), and the concomitant observation of a large aggregation on the seaward side of South Passage, suggest that most of the dugongs had moved from their feeding grounds into more oceanic water. The unusually cold weather could provide a plausible explanation of this behaviour. (The lowest daily maximum temperature for the area for 7 years was recorded on 6 June.) Unfortunately, sea surface temperatures in the survey area were not measured during this survey, but the temperature of the adjacent oceanic water dropped 3°C between 2 and 7 June (data not available for 8 June) (Fig. 2). The only June day for which surface water temperature data for both areas are available is 9 June 1976, when the water temperature on the seaward side of Stradbroke Island was 3°C higher than on the sandbanks. Anderson (1986) observed dugongs concentrating in tongues of warm oceanic water during the winter in Shark Bay, Western Australia, which is at a similar latitude to Moreton Bay.

Aerial surveys designed to obtain absolute estimates or indices of dugong abundance should be designed to cover areas large enough to accommodate such movements.

Acknowledgments

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