

Fixed-width Aerial Transects for Determining Dugong Population Sizes and Distribution Patterns

by

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Abstract. The fixed-width transect technique developed for surveying the dugong (*Dugong dugon*) from the air at large spatial scales (tens of thousands of km²) is described and evaluated. Perception bias (the proportion of groups that is visible in the transect, yet missed by observers) is corrected with a modified Petersen estimate calculated for each of two teams of tandem observers, one on each side of the aircraft. Availability bias (the proportion of animals that is unavailable to observers because of water turbidity) is standardized by comparing the proportion of individuals at the surface during the survey with the proportion at the surface in a clear-water area when all dugongs are potentially visible. This fixed-width transect technique provides a standardized estimate of minimum population size and is useful for producing density-distribution maps for monitoring trends in abundance over large spatial scales and long time periods, and for assessing the probable impact of direct anthropogenic mortality. However, the population size estimated with the technique has a coefficient of variation (S.E./mean) of 12% at best, which means detection of a low-level chronic decline in dugong abundance even at a large spatial scale would take about one decade.

Key words: Aerial survey techniques, bias corrections, dugong, *Dugong dugon*.

The range of the dugong (*Dugong dugon*) extends throughout the tropical and subtropical coastal and island waters of the Indo-west Pacific from east Africa to the Solomon Islands and Vanuatu and between 26° and 27° north and south of the equator (Nishiwaki and Marsh 1985). The distribution spans the waters of more than 40 countries. Over much of this range, dugongs are now believed to be represented by relict populations, separated by large areas in which they are close to extinction or extinct (Nishiwaki and Marsh 1985) or have never occurred. For most countries, however, this assessment is based on anecdotal information and the extent of population declines or range contractions is unknown because quantitative information on the distribution and abundance of dugongs and their habitats is unavailable.

The only quantitative information on dugong population size is from aerial surveys. Hughes and Oxley-Oxland (1971) demonstrated that aerial surveys were useful for studying dugongs in Mozambique. Heinsohn et al. (1976) were the first to survey dugongs from the air in Australia, and most surveys have been in Australian waters. Aerial

surveys of dugongs have also been conducted in Kenya (*¹Ligon 1976), Papua New Guinea (Ligon and Hudson 1977; Hudson 1980a, 1980b), Palau (*Brownell et al. 1981; Rathbun et al. 1988), Irian Jaya in Indonesia (*Salm et al. 1982), the Arabian region (*Preen 1989), and Vanuatu (Chambers et al. 1989).

The designers of the surveys before 1983 assumed that, because dugongs feed primarily on seagrasses (Marsh et al. 1982), they mainly occur in coastal waters within about 2 km of land. The survey technique was broadly similar to the extended-area technique (sensu *Packard 1985 and Lefebvre et al. 1995) used for manatees (*Trichechus manatus latirostris*). Dugongs were counted from aircraft at altitudes of 275–300 m and about 0.8 km from and parallel to the shore. If a large group of dugongs was detected, a count was made while the aircraft circled. In some studies, flights were made over additional transects where suitable habitat was known to extend farther offshore. No corrections were made for dugongs that were not seen by observers (e.g., because of water turbidity).

This technique proved useful for identifying areas in which large numbers of dugongs occurred close to the shore (see Nishiwaki and Marsh [1985] for a summary of

¹ An asterisk denotes unpublished material.

Appendix B. Continued.

Survey date	Survey conditions					Counts	Cumulative degree days								
	A ^a	A3 ^b	W ^c	W3 ^d	SC ^e		S ^f	-5 ^g	-10	-15	-20	-25	-30	-35	-40
891210	14	19	21	21	2	113	42	10	34	35	36	42	42	42	42
891214	11	15	20	21	2	113	68	35	44	62	62	62	68	68	68
891224	2	7	17	19	3	126	133	61	65	99	109	126	126	127	133
891226	11	6	14	16	2	198	169	97	97	121	135	161	162	163	169
90 115	20	15	20	20	3	134	211	23	23	25	43	139	140	163	178
90 228	20	19	22	22	3	21	228	8	8	8	9	9	9	17	17
901210	14	15	21	21	2	186	37	28	35	35	35	35	37	37	37
91 123	16	17	21	21	3	26	82	10	19	23	23	23	25	25	25
91 213	19	18	21	22	4	26	93	10	10	10	11	21	26	34	34
91 217	13	13	21	21	3	80	120	28	38	38	38	39	48	58	62

^a Air temperature (° C) on day of survey.

^b Average air temperature (° C) for 3 days prior to survey.

^c Water temperature (° C) on day of survey at power plant intake.

^d Average intake water temperature (° C) for 3 days prior to survey.

^e Index to flight and sighting conditions during survey.

^f From start of winter (1 Nov) to survey date.

^g -5, ..., -40 are starting points in days relative to the survey date.

^h Survey unusable for analysis.

counts in various areas). Because of its ease of implementation, the technique is still useful for identifying inshore areas in developing countries where dugongs occur, particularly in regions where the continental shelf is narrow (Chambers et al. 1989).

Dugongs have been sighted tens of kilometers from the coast in large embayments (e.g., Shark Bay in Western Australia; *Marsh et al. 1991; Marsh et al. 1994) and where the continental shelf is broad (e.g., Torres Strait [Marsh and Saalfeld *1988, *1991] and the northern Great Barrier Reef lagoon [Marsh and Saalfeld 1989]). The number of dugongs sighted during a survey over the shoreline is an unreliable index of abundance because it depends on the degree to which the distribution of the animals follows the coast, which is variable, even where the continental shelf is narrow. Hence, the shoreline method is unsuitable for tracking temporal changes in dugong abundance, especially at large spatial scales.

The shoreline technique has largely been replaced by fixed-width transect surveys (Marsh and Saalfeld 1989; Marsh and Sinclair 1989a, 1989b) designed to provide standardized minimum population-size estimates of dugongs as a basis for monitoring temporal changes in abundance, for the assessment of the impact of direct anthropogenic mortality, and for density-distribution maps at scales required for management by zoning. A fixed-width transect technique was adopted in preference to the line transect technique often used for dolphin surveys (Forney et al. 1991). Dugongs are generally more difficult to sight than dolphins because they are most often seen as solitary individuals or adult female-calf pairs in turbid water. Accordingly, we decided to use a technique with which observers did not have to take their eyes off the water to read an inclinometer.

Here I review the fixed-wing transect technique as a background to the evaluation of the relevance of dugong aerial-survey techniques for estimating manatee population sizes or trends.

Material and Methods

Survey Procedure

Dugongs are counted on either side of an aircraft flying at 185 km/h at an altitude of 137 m over 200-m-wide strip transects. Altitude is maintained with the aid of a radar altimeter. The strip transects, defined by markers on the wing struts (see diagram in Caughley 1977), are sufficiently narrow to preclude detectable variation in dugong sightability across the transect (Marsh and Saalfeld 1990).

The survey crew comprises six people: the pilot, a front-right survey leader, and two teams of tandem observers, one on either side of the aircraft. The survey leader

records the data with a portable computer programmed as a data logger and timer and equipped with a printer that produces an immediate hard copy of the data. The mid-seat observers report their sightings to the survey leader via a 2-way intercom system connected to one track of a 2-track tape recorder. The rear-seat observers are usually screened from the mid-seat observers with a curtain and acoustically isolated from the other crew members but can communicate with each other. They report their sightings into the second track of the tape recorder (Fig. 1).

All reports from observers are in standardized format: dugong group size, number of calves, number at the surface, and position of the sighting inside the transect strip. The top (farthest from aircraft), middle, and bottom thirds of the transect are color-marked on the wing strut to facilitate the determination of the position of sightings inside the strip. This information is recorded to increase the probability of distinguishing between different, simultaneously reported sightings by both members of a tandem team. Surveys are made only when the cloud cover is less than 50% and the sea is calm (<Beaufort 3); they are timed to minimize glare off the surface of the water from a low or mid-day sun.

After each flight, the tape record of each transect is used to verify and edit the computer records, so that each sighting can be coded as made by one (specified) member or both members of a tandem observing team. The reports of team members are different if they are unambiguously distinct (usual situation) or if they are separated by 5 or more seconds. Discrepancies between the reports of observers sighting the same group of dugongs are also noted.

When training a new observer (Marsh and Saalfeld 1989), I use a functional tandem team on one side of the aircraft and one trained observer and the trainee on the other side. During training, the intercom system is switched so that the trainee can hear the reports of his or her counterpart on the same side of the aircraft. This system greatly reduces the time to train reliable observers.

Corrections are made for perception bias (dugongs that are visible but missed by observers) and availability bias (dugongs that are unavailable to observers because of water turbidity) with correction factors that are calculated separately for each survey. These corrections compensate for fluctuations in variations in the visibility biases that are due to changes in sea state, glare, and water turbidity within the range of acceptable survey conditions and that cannot be eliminated by the standardization of procedures. They also compensate for differences between observers and reduce the need to use the same observers for each survey.

The correction for perception bias is based on a modified Petersen estimate calculated separately for the two

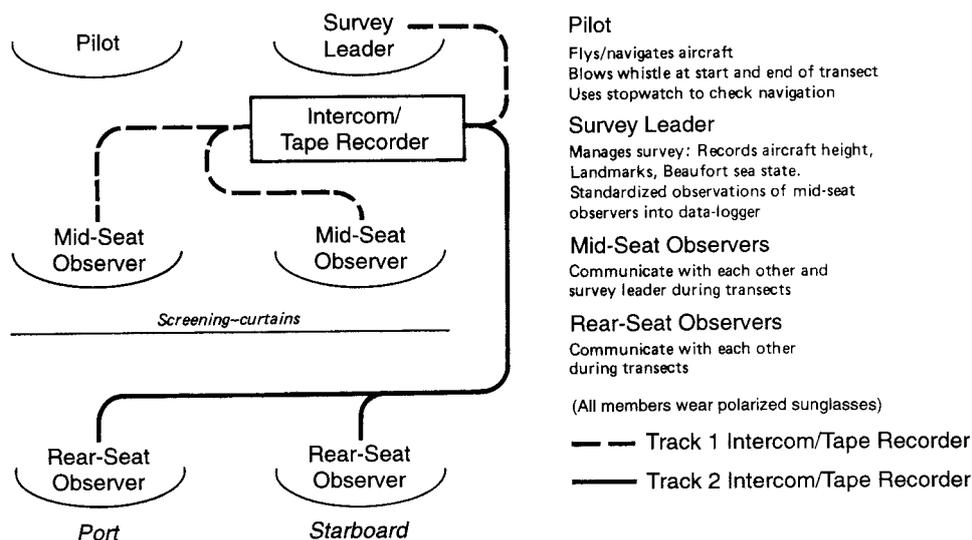


Fig. 1. The arrangement and duties of the survey crew during fixed-width aerial transect surveys of dugongs (*Dugong dugon*).

teams of two observers (Marsh and Sinclair 1989a). This correction factor requires the assumption that all groups are equally sightable. Marsh and Sinclair (1989b) showed that this is a reasonable assumption for the small groups of dugongs usually observed.

The correction for availability bias (Marsh and Sinclair 1989a) serves to standardize the results of each survey for the proportion of animals that was unavailable to observers because of water turbidity during that survey. This correction rests on the untested assumption that the proportion of dugongs at the surface is constant within the limits of acceptable survey conditions. This proportion (16.7%) is based on data from an aerial survey over a clear water area in Moreton Bay near Brisbane where all dugongs were assumed to be visible. The proportion is not significantly different from that obtained from vertical aerial photographs of dugongs in the same area (Marsh and Sinclair 1989b). This fraction is, however, much greater than the 1.9% suggested by Anderson and Birtles' (1978) surface observations of diving and surfacing dugongs in muddy water. The differences may be due to the observation platform or spatial variation in diving by dugongs. I believe the corrections for availability bias are probably conservative and the population size obtained with the fixed-wing transect technique is probably underestimated.

Large Groups of Dugongs

The mean size of a group of dugongs sighted in these surveys is between 1.3 and 2.1 animals (Marsh and Sinclair 1989a). Groups of more than 10 dugongs are rare (<2% of groups; Marsh and Saalfeld *1988, 1989, 1990; *Marsh et al. 1990, *1991, 1994). When these groups are sighted (even outside the transect), the flight course is

interrupted and the group is circled and photographed to obtain a total count. These groups are then treated as a separate stratum of large herds as suggested by Norton-Griffiths (1978).

Survey Design

The survey areas ranged from about 2,000 to 40,000 km² (Table 1). Each area was divided into blocks (sampling strata) based on expected dugong density. The sampling fraction in each block was proportional to dugong density, varying from about 5% where few dugongs were expected to about 20% where the known dugong density was high. The sampling fraction in the entire survey usually averaged about 10%. Dugongs in each block were sampled over systematically spaced transects (the first transect was placed randomly). Because of their logistical advantages and to facilitate the production of density-distribution maps, systematic rather than random transects were used. The transects were aligned across the depth contours to increase the precision of the population-size estimates. The same transects were used on repeated surveys of the same area so that transects could be used as factors in the analyses. I now use a global positioning system to locate the aircraft on the transects.

Analysis

Because transects are variable in area, the Ratio Method (Jolly 1969; Caughley and Grigg 1981) was used to estimate density and population size and their associated standard errors in each block in each survey. Any statistical bias from this method was considered inconsequential because of the high sampling fraction

Table 1. Estimates of the number and densities of dugongs (*Dugong dugon*) and the associated coefficients of variation where surveys were conducted with the fixed-width transect technique.

Location	Area (km ²)	Population estimate ±S.E.	Density km ⁻¹ ±S.E.	Coefficients of variation	Reference
Shark Bay ^a	14,240	10,146± 1,478	0.71± 0.10	14.6	*Marsh et al. (1991) Marsh et al. (1994)
Exmouth Gulf- Ningaloo ^a	3,397	1,964± 363	0.58± 0.11	18.5	*Marsh et al. (1991)
North coast Northern Territory ^b	28,746	13,800± 2,683	0.48± 0.09	19.4	Bayliss (1986) in Bayliss and Freeland (1989)
Western Gulf of Carpentaria ^b	27,216	16,846± 3,259	0.62± 0.12	19.3	Bayliss and Freeland (1989)
Torres Strait ^c	30,533	12,522± 1,497	0.41± 0.05	11.9	*Marsh and Saalfeld (1988 and 1991)
Northern Great Barrier Reef ^c	31,288	8,110± 1,073	0.26± 0.03	13.2	Marsh and Saalfeld (1989)
Southern Great Barrier Reef ^c	39,396	3,479± 459	0.088± 0.012	13.2	Marsh and Saalfeld (1990)
Southeast Queensland ^c	9,170	2,479± 365	0.26± 0.04	14.7	*Marsh et al. (1990)
Arabian Gulf ^d	34,604	7,310± 1,300	0.25 ^e ± 0.045	17.8	*Preen (1989)
Saudi Arabian coast of Red Sea	22,370	1,820± 380	0.08 ^e ± 0.017	20.9	*Preen (1989)

^a Western Australia.^b Northern Territory, Australia.^c Queensland, Australia.^d Saudi Arabia.^e Excluding zones in which too few dugongs were sighted for population-size estimates.

(Caughley and Grigg 1981). Input data were the estimated number of dugongs (in groups of <10) for each tandem team per transect, calculated with the corrections for perception and availability biases. The resultant standard errors were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and mean group size as outlined in Marsh and Sinclair (1989a). At the end of the analyses, the number of dugongs in groups of more than 10 was added to the estimates of the population size and density in the appropriate block, as outlined in Norton-Griffiths (1978).

Density diagrams, adjusted for sampling intensity, were produced with the Arcinfo GIS package. A grid coverage (2.5 km² or 5 km²) was combined with the coastline coverage. The corrected number of dugongs and the transect length in each grid cell were calculated. The density in each grid cell was then calculated as follows:

density/km² = corrected number of dugongs sighted in cell/survey area in cell, where survey area = transect length in km × transect width (i.e., 0.4 km).

Results

Distribution of Dugongs

Density distribution maps were produced for the entire survey area (Table 1). High local densities of dugongs occur in inshore waters sheltered from trade winds and in association with offshore reefs and shoals in the northern Great Barrier Reef (Marsh and Saalfeld 1989; *Marsh et al. 1993) and Torres Strait (Marsh and Saalfeld *1988, *1991). Large numbers of dugongs were sighted in more-than-10-m-deep water in several areas including Shark Bay in Western Australia (*Marsh et al. 1991; Marsh et al. 1994), Torres Strait (Marsh and Saalfeld *1988, *1991), the northern Great Barrier Reef region (Marsh and Saalfeld 1989; *Marsh et al. 1993), and Hervey Bay in southeastern Queensland (*Marsh et al. 1990). The proportion of dugongs in these deeper water areas is unknown because we lack information on the relation between diving and surfacing times at different depths. In contrast to their essentially inshore distribution where the continental shelf is narrow, dugongs seen in waters deeper than about 10 m in northern Australia tend to be more than

10 km from land (Marsh and Saalfeld *1988, 1989, *1991; Marsh et al. *1990, *1991, *1993, 1994).

Detection of Population Trends

Temporal changes in density have been studied with repeated surveys of dugongs in the same area and with analysis of variance usually with and without measures of sea state or cloud cover at each transect as continuously distributed covariates (Bayliss and Freeland 1989; Marsh and Saalfeld 1989; *Marsh et al. 1993). Blocks and times were treated as fixed factors and transects as a random factor nested within blocks. Data for all analyses were corrected densities/km² based on mean group sizes and the estimated correction factors for perception and availability bias; each transect contributed one density per survey based on the combined corrected counts of both tandem teams. The densities were transformed ($\log_{10}x + 1$) for analysis to equalize the error variances.

The population-size estimates (Table 2; Fig. 2) are consistent, especially in surveys separated by relatively short time intervals (months). The inclusion of sea state and cloud cover as covariates in the analyses made little difference to the results and did not alter the conclusions (Marsh and Saalfeld 1989), suggesting that the method was appropriate for stabilizing most biases in visibility because of weather conditions.

Marsh and Saalfeld (1989) used Gerrodette's (1987) power analysis technique to investigate the length of time to detection of a hypothetical population decline of 5%/year with acceptable levels of confidence (Type 1 and Type 2 errors at 0.05). Assuming that the precision of the population-size estimate is 11% (which is optimistic even for large-scale dugong surveys at the given sampling fractions; Table 1), Marsh and Saalfeld (1989) estimated that 10 annual surveys are required (i.e., 9 years to be able to detect such a decline with 95% confidence). During this period, a dugong population declining at 5%/year would have been

reduced to 63% of its size since the time of the first survey. A preliminary indication of this trend could be obtained more quickly by increasing the Type 1 and Type 2 error rates. However, because the consequences of failing to detect a declining trend are more serious than the consequences of deciding that a declining trend is occurring when it is not, the Type 2 error rate must be kept low. Even if the Type 2 error rate were increased to 0.1 and the Type 1 error rate to 0.15, eight annual surveys (7 years) are required to detect a declining trend in the given example.

Discussion

Evaluation of the Technique

Results of the fixed-width transect technique are now used for developing local strategies for dugong conservation. Density-distribution maps of dugongs are used for the zoning and management of marine protected areas in northern Australia, especially in the Great Barrier Reef Marine Park. Distribution maps have also been used to produce recommendations for the conservation and management of dugongs in the Arabian region (*Preen et al. 1989). The distribution of dugongs mirrors the distribution of seagrasses in all survey areas. Indeed, the pattern of dugong sightings has proved a reliable basis for designing recent seagrass surveys in Torres Strait, the northern Great Barrier Reef, and Shark Bay.

The standardized minimum population-size estimates have been used in conjunction with a dugong population model to assess the probable impact of direct anthropogenic mortality of dugongs in the few cases for which a measure of that mortality was available. For example, Smith and Marsh (1990) concluded that the take of Aboriginal communities in Cape York was well below the sustainable yield.

In Australia, dugongs are being resurveyed at regular intervals along fixed transects using the techniques outlined

Table 2. Comparison of the population-size estimates obtained from repeated surveys of dugongs (*Dugong dugon*) with the fixed-width transect technique in the same area.

Location	Survey date	Population estimate \pm S.E.	Reference
Western Gulf of Carpentaria ^a	August 1984	16,816 \pm 2,946	Bayliss and Freeland (1989)
	February 1985	16,846 \pm 3,257	
Cape Bedford-Cape Melville ^b	November 1984	2,899 \pm 454	Marsh and Saalfeld (1989)
	November 1985	2,542 \pm 634	
Campbell Point-Hunter Point ^b	April 1985	2,172 \pm 552	Marsh and Saalfeld (1989)
	November 1985	1,938 \pm 491	
Cape Bedford-Hunter Point ^b	November 1985	8,100 \pm 1,073	Marsh and Saalfeld (1989)
	November 1990	10,742 \pm 1,579	*Marsh et al. (1993)

^a Northern Territory, Australia.

^b Northern Great Barrier Reef region, Queensland, Australia.

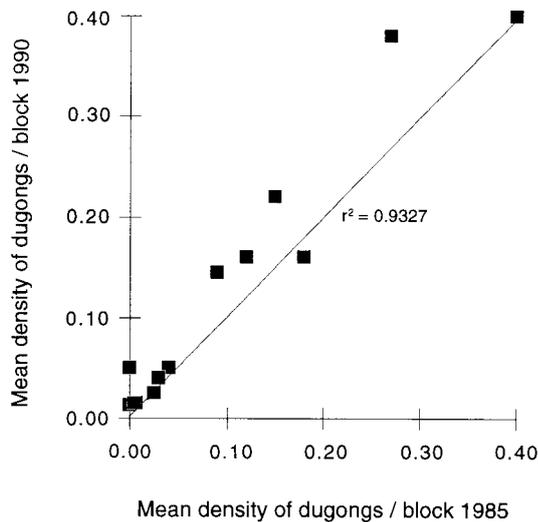


Fig. 2. The estimated density of dugongs (*Dugong dugon*) in each block in the northern Great Barrier Reef region in Australia in 1985 (Marsh and Saalfeld 1989) plotted against the estimated numbers in the same blocks when the survey was repeated in November 1990 (Marsh et al. 1993). The line illustrates equal densities in the two surveys and is not the fitted regression line represented by the r^2 value.

in this paper. I recommended a resurvey interval of 5 years to the management agencies. Although the expected small population-size changes will probably not be detected in less than a decade, a 10-year interval between surveys could cause unwarranted delays in the management response if numbers were declining rapidly. In addition, personnel changes would make it difficult to guarantee continuity of the methodology if the survey interval was much longer than 5 years.

The greatest weakness of the technique is its dependence on the unvalidated assumption that the proportion of dugongs on the surface is constant. Data are urgently needed to examine this assumption and, if it is incorrect, to develop additional methods of compensating for the variability in the proportion of dugongs that are not visible to observers.

The method also must be modified so that local changes in dugong densities can be monitored, a modification that may be relevant to the needs of surveying manatees in large bays, lagoons, and estuaries. Theoretically, this goal can be achieved by increasing the sampling fraction and the frequency of surveys, which have yet to be empirically confirmed.

Applicability of the Technique to Surveys of Manatees

Lefebvre et al. (1995) provided a corresponding review of techniques and problems with surveys and current methods of estimation of population sizes of Florida manatees.

Manatees inhabit rivers or coastal and estuarine waters and seemingly require access to freshwater (Hartman 1979), whereas dugongs are strictly marine and in some areas feed tens of kilometers offshore. Thus the spatial dimensions tend to be more linear in manatee habitats than in dugong habitats. The spatial design of manatee surveys must reflect these differences, and parallel transects probably will be useful only in large bays, estuaries, and lagoons. However, the distinction between perception and availability bias (Marsh and Sinclair 1989a) is relevant to manatee surveys, and the methods developed to overcome these biases in dugong surveys have potential application for surveys of manatees.

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