Spatial and temporal variation in counts of the Antillean manatee (*Trichechus m. manatus*) during distribution surveys at Bahia de Chetumal, Mexico

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Abstract

Obtaining a measure of the abundance and distribution of manatees (*Trichechus manatus*) is essential for the management and conservation of this species. Aerial surveys are the most suitable method for monitoring manatee numbers, and near shore single flights have been used in most of Latin America countries. Based on the results from 17 flights conducted between November 1998 and May 2000 in Bahia de Chetumal, Mexico, designed to determine manatee-habitat relationships, we review some weaknesses of past survey strategies as valid indicators of manatee distribution and relative abundance along the coast. Even though visibility conditions were very good in the surveyed area, intra-seasonal variation was large, precluding powerful seasonal comparisons. No significant differences were found among seasons. There was a significant difference between zones with higher values of density near shore. The overall density dropped to 17–32% over 1 km from the coastline. The results confirm that single surveys are poor indicators of abundance and distribution, and that depth must be included, along with distance from shore, to design surveys of distribution.

Key words: Antillean manatee, *Trichechus manatus manatus*, aerial surveys, Bahia de Chetumal, Mexico, spatial variability, temporal variability.

Introduction

The Antillean manatee (*Trichechus manatus manatus*) has been subject to intense hunting pressure since contact by Europeans, leading to populations decreases, while current human activities and use of the coastal areas continue to threaten the habitat of this species. The reduction in manatee populations and habitat has promoted its legal protection in most of the countries that have viable habitat, as well as efforts to study remaining populations and habitat.

One important research and management goal is the measurement of the actual number of manatees and the quality and extent of the areas they occupy. The most suitable method to obtain an indication of their abundance and distribution over large areas has been counting them from light, high-wing, aircraft (Ackerman, 1995; Lefebvre *et al.*, 1995). Given the difficulties associated with conducting distance sampling on line transects during aerial surveys in aquatic habitats for species, like manatees, strip-transects have been used instead (Lefebvre *et al.*, 1995; Marsh, 1995; Miller *et al.*, 1998). This type of survey is thought not to yield exact estimates of manatee abundance, but results are used as indices of population abundance to focus research and conservation issues. It is intuitive that several surveys are better than a single one, but the high cost of conducting aerial surveys compared to available research and conservation funds, has obligated that, in Mexico and most Central American and Caribbean countries, surveys are conducted without replications and without correction for bias.

The most important manatee population on the coasts of the Yucatan Peninsula occurs in Bahia de Chetumal and adjacent Belize (Bengston & Magor, 1979; Colmenero-Rolón & Zárate-Becerra, 1990; O'Shea & Lex'Salisbury, 1991; Morales-Vela & Olivera-Gómez, 1997; Morales-Vela *et al.*, 2000). Here, manatees have been counted in 0.8–1 km wide strips along the coastline since 1987 (Colmenero-Rolón & Zárate-Becerra, 1990; Morales-Vela & Olivera-Gómez, 1992; Morales-Vela *et al.*, 2000). Except on two flights conducted specifically to estimate population size, no perpendicular transects have been flown (Morales-Vela & Olivera-Gómez, 1994). Furthermore, only one

flight, at most, per season was carried-out in all studies.

We use the results of 17 flights, involving repeated counts within four sampling seasons, designed to evaluate the association between manatees and habitat features in Bahia de Chetumal. Our main goal here is to review some assumptions implied in past manatee surveys in Latin America and analyze the value of much efforts as a reliable indicator of abundance. Our surveys included areas more than 1 km from the coastline, to provide a better picture of the distribution of manatees in the area. Surveys in Central and South America, and in the Caribbean, have followed the same protocol used in Mexico (Bengston & Magor, 1979; Rathbun *et al.*, 1983; 1985; O'Shea & Lex'Salisbury, 1991; O'Shea *et al.*, 1988; Morales-Vela *et al.*, 2000; Mou-Sue & Chen, 1990; Reynolds *et al.*, 1995), thus we expect our analysis to be useful in improving survey design in those areas as well.

Materials and Methods

This study was carried-out in the northern section of Bahia de Chetumal, Mexico (Fig. 1). Most of this area has clear and shallow waters and a good contrast between substrate and manatees. These characteristics provide good conditions for aerial surveys almost year-round.

Bahia de Chetumal lies in a S-N direction over a line of geological faults, and covers approximately 1098 km^2 (*ca.* 80 km long and 25 km width). Most of the bay is about 3 m deep (Morales-Vela *et al.*, 1996), but it deepens to a natural channel that reaches depths of 15 m along the central axis (Olivera-Gómez, unpublished data).

The bay is fed by numerous freshwater sources. The Hondo and New rivers empty into the bay in its middle section. The Bacalar-Laguna Guerrero system, composed of lakes and wetlands, empties into the northwest coast of the bay and is the main source of freshwater to the study area. The Rio Creek wetland system drains into the northern end of the bay, linking the bay with the southern end of the Sian Ka'an wetlands (Ortíz-Pérez & Méndez-Linares, 1995). Finally, a small wetland system, Siete Esteros, empties into the northeastern coast of the bay.

The salinity in the bay ranges from 18 practical salinity units (psu) in the southeastern end to 4 psu in the northeastern end (Morales-Vela *et al.*, 1996). In the study area, salinity ranges between 4 and 10 psu. The mean water temperature is 28°C, with a minimum of 22°C in January and February, and a maximum near 31°C in August (Morales-Vela *et al.*, 1996). The dry season extends from February to June. The rainy season is from July to October, with a mid-summer moderate drought in August. Precipitation decreases from November to January. Submerged vegetation in the bay is composed of shoal grass (*Halodule wrightii*), turtle grass (*Thalassia testudinum*), widgeon grass (*Ruppia maritima*), water nymph (*Najas marina.*), and macroalgae (*Bathophora oerstedii*, and *Chara chara*) (Morales-Vela *et al.*, 1996).

Between November 1998 and April 2000, we conducted 17 aerial surveys for manatees in the northern section of Bahia de Chetumal, in four sampling periods: (a) three flights in November 1998, (b) four flights in May–June 1999, (c) five flights in August-September 1999, and (d) five flights in April–May 2000. Sampling periods b and d fell within the typical dry season and the other two (a and c) during wet months. We flew in a fixed, high-wing, Cessna-182 airplane, at an altitude of 150 m and a speed of 180 km/h, typical of manatee and dugong surveys (Shane, 1983; Rathbun *et al.*, 1990; Provancha & Hall, 1991; Lefebvre *et al.*, 1995; Marsh, 1995; Morales-Vela & Olivera-Gomez, 1994; Morales-Vela *et al.*, 2000). All surveys were conducted with a Beaufort's sea state less than three, cloud cover less than 50%, and wind speed not exceeding 20 km/h. The flight followed a series of transects parallel to the coast, covering the west and east coasts of northern Bahia de Chetumal, starting at the Chetumal City Airport (Fig. 2). Each survey lasted about 1 h and 15 min of total flight time.

The survey crew consisted of two observers in the rear seats of the craft and a pilot and another observer in the front seat. The front observer was the more experienced and coordinated the flights. Rear left and front right observers remained the same throughout the study. Observers wore polarized sunglasses to reduce glare from the water. Each observer scanned a 400 m wide zone, the inner edge given by the limit of the observer's vision below the aircraft and the outer edge by a strip of tape affixed to the aircraft window. The with of the transect was achieved with an angle of 71°32′ from below; however, ground correction for each observer was performed. All sightings, as well as the flight path, were recorded with a GPS with an external antenna on the front window of the plane. The number of manatees and details about sightings were recorded into hand-held tape recorders.

A sighting consisted of one or more manatees. When more than one manatee were observed in the same area, we considered them as a single sighting if they were less than 50 m apart. A manatee was recorded as on the surface if it was on or immediately below the surface. In most of the area, manatees could be seen to depths of 4 or 5 m.

The study area was divided into two zones, within and outside the 4-m isobath (shallow and
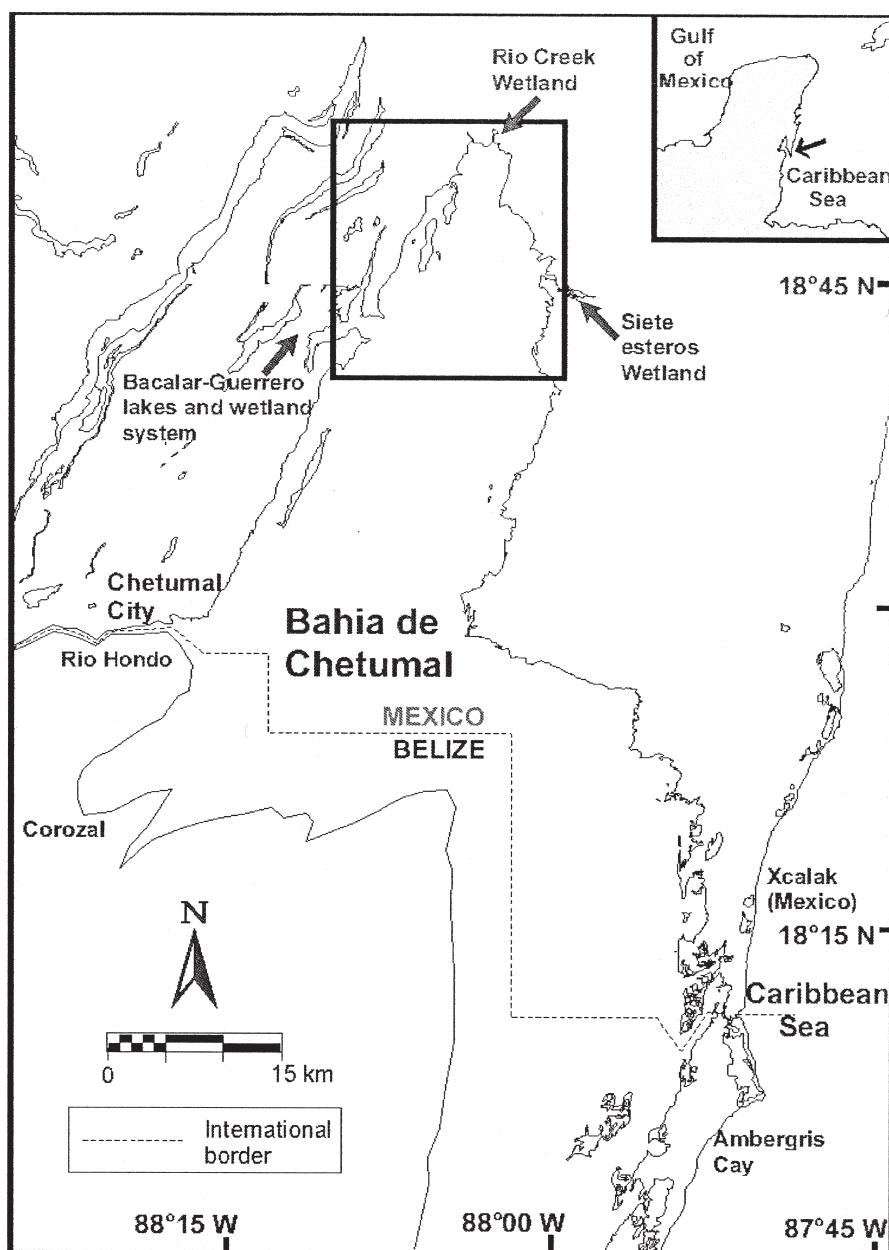
Figure 1. Bahia de Chetumal, in southernmost Quintana Roo, Mexico. The study area at the northern section of this bay is showed enclosed within a box.

deep zones, respectively). The shallow zone was further divided into areas less and more than 1 km from the coastline (near and far, respectively) (Fig. 2). Statistical tests were performed only for the two shallow zones, because manatees in deeper waters have lower detectability (Lefebvre *et al.*, 1995) and a different sighting probability that was not estimated.

Data for the two shallow zones were pooled to test, with a one-way ANOVA, the hypothesis that there were no differences among seasons in the mean number of manatees (individuals) per km^2 or
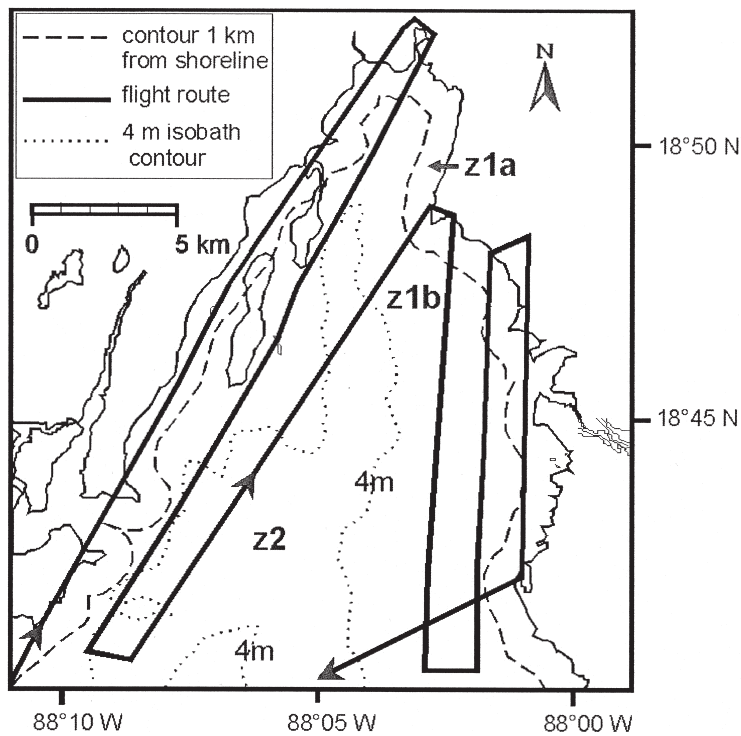
Figure 2. Typical flight path followed on manatee aerial surveys conducted in this study in northern section of Bahia de Chetumal, Mexico. It is shown the 4–m isobath and the different zones surveyed (z1a, z1b, and z2). The dotted line, along the shore, separates waters within and beyond 1 km from the coastline.

in sightings (of one or more individuals) per km^2. We used a two-way ANOVA, with seasons as the random factor and zones as fixed factors, to test the hypotheses that: (a) there was no variability in the sightings rate or in density among sampling seasons (*sensu* Bennington & Thayne, 1994); (b) there were no differences in the mean sightings rate and density between the two zones; and (c) the variability in the sightings rate and density among sampling seasons was the same for the two zones. We checked for normality by graphical examination of residuals, and for homogeneity of variances using Bartlett's test (Zar, 1984). For the statistical analysis, we used the computer software Minitab$^{®}$ (vers. 13.3, Minitab Inc., 2000).

Results

We recorded 350 manatees in 214 sightings (an average of 20.6 manatees and 12.6 sightings per survey) in all three zones surveyed (Table 1). The maximum size of a group was 12 individuals. The distribution of group size (by number) was: 1(153), 2(33), 3(11), 4(7), 5(3), 6(3), 7(1), 8(1), 9(1), 12(1). Therefore, groups less than 3 manatees were the

92.1% of recorded sightings. The overall mean density was 0.240 manatees per km^2 and the mean sighting rate was 0.149 sightings per km^2. Figure 3 exhibits the location of all sightings recorded on each season. Locations of manatees were aggregated in some areas, but, in general, manatees occupied the entire area (Fig. 3). In the summer of 1999, manatees were more dispersed than in the other sampling periods (Fig. 3).

In the deeper zone, we recorded between 3.1 and 13.1% of the total sightings per season (Table 1). These values; however, could be underestimates because of the lower detectability of manatees submerged in deep waters (Lefebvre *et al.*, 1995). In our study, 42% of the manatees in shallow zones were at or near the surface. However, without more information about the use of deeper water in the area we cannot use this proportion to correct for counts in the latter area.

There were no seasonal statistical differences in the number of sightings per km^2 ($P=0.928$) or in the number of manatees per km^2 ($P=0.798$) for the two shallow zones pooled (Table 1, Fig. 4). However, the power of the test to detect differences among data was too low (0.1), with these data the

Table 1. Manatees aerial survey results for the four seasons sampled on each of the three zones surveyed in the northern section of Bahia de Chetumal. Results from zone 1a and 1b are shown separately and together. Values are means ± one standard deviation.

	Season				
	Nov 1998	May–Jun 1999	Aug–Sept 1999	Apr–May 2000	all seasons
No. flights	3	4	5	5	17
Zone 1a					
No. sightings	6.0 ± 2.6	8.0 ± 2.7	8.0 ± 4.4	7.2 ± 2.4	7.4 ± 3.0
No. manatees	8.7 ± 6.4	16.0 ± 10.8	14.4 ± 8.6	11.6 ± 6.1	12.9 ± 7.8
km^2 covered	33.1 ± 1.2	32.5 ± 3.1	36.3 ± 1.4	27.2 ± 1.0	32.2 ± 4.0
Sightings per km^2	0.181 ± 0.080	0.243 ± 0.070	0.220 ± 0.116	0.263 ± 0.082	0.231 ± 0.087
Manatees per km^2	0.263 ± 0.193	0.473 ± 0.297	0.401 ± 0.241	0.422 ± 0.210	0.403 ± 0.237
Zone 1b					
No. sightings	4.3 ± 3.5	3.8 ± 0.5	5.2 ± 3.3	3.4 ± 2.5	4.2 ± 2.5
No. manatees	5.3 ± 3.8	5.8 ± 2.1	9.0 ± 5.7	5.4 ± 2.5	5.9 ± 4.2
km^2 covered	42.6 ± .1	50.6 ± 2.9	50.0 ± 1.4	38.9 ± 2.3	45.6 ± 5.6
Sightings per km^2	0.102 ± 0.082	0.074 ± 0.012	0.105 ± 0.067	0.088 ± 0.066	0.092 ± 0.057
Manatees per km^2	0.125 ± 0.089	0.115 ± 0.046	0.180 ± 0.115	0.088 ± 0.066	0.128 ± 0.085
Zones 1a and 1b					
No. sightings	10.3 ± 5.9	11.8 ± 2.6	13.2 ± 6.3	10.6 ± 2.4	11.6 ± 4.3
No. manatees	14.0 ± 9.2	21.8 ± 12.7	23.4 ± 13.1	15.0 ± 5.6	20.1 ± 10.6
km^2 covered	75.7 ± 1.2	83.1 ± 2.9	85.7 ± 1.7	66.1 ± 2.8	77.7 ± 8.8
Sightings per km^2	0.137 ± 0.078	0.141 ± 0.030	0.153 ± 0.073	0.160 ± 0.035	0.150 ± 0.052
Manatees per km^2	0.185 ± 0.121	0.259 ± 0.147	0.272 ± 0.155	0.225 ± 0.077	0.258 ± 0.126
Zone 2					
No. sightings	0.3 ± 0.6	1.0 ± 1.4	0.8 ± 1.1	1.6 ± 1.1	1.0 ± 1.1
No. manatees	0.3 ± 0.6	2.0 ± 3.4	0.8 ± 1.1	3.2 ± 4.0	1.7 ± 2.8
km^2 covered	6.2 ± 0.7	10.2 ± 6.1	13.7 ± 2.1	13.5 ± 1.7	11.5 ± 4.2
Sightings per km^2	0.048 ± 0.083	0.065 ± 0.088	0.057 ± 0.081	0.116 ± 0.075	0.096 ± 0.118
Manatees per km^2	0.048 ± 0.083	0.127 ± 0.209	0.057 ± 0.081	0.220 ± 0.245	0.142 ± 0.192

Note: zone 1a <1 km from the shoreline; zone 1b >1 km from the shoreline but <4m deep; zone 2 >4 m deep.

minimum detectable differences in density with a power of 0.9 was 0.346 manatees per km^2. With the two-way ANOVA, we found no variability in the number of sightings per km^2 ($P=0.862$) or in the number of manatees per km^2 ($P=0.721$) among seasons. The shallow zone nearest to the shore (zone 1) had a mean sighting rate (0.231) and density (0.403) significantly higher ($P=0.008$; and $P=0.012$, respectively) than the zone farthest from shore (0.092 and 0.128, respectively; Table 1). When we tested the interaction of seasons and zones, we found the same variability in the number of sightings per km^2 and in the number of manatees per km^2 ($P=0.604$; and $P=0.627$, respectively) for both levels.

Coefficients of variation (CV) within each season were high. When the sighting data from the shallow zones were pooled, the CV for the number of manatees per km^2 varied from 34.4 to 65.5%, and for the number of sightings per km^2 CV ranged from 20.9 to 56.8%. The lowest CV was for the number of sightings per km^2 in May–June 1999 and April–May 2000.

Discussion

Our surveys were not intended to achieve a precise estimate of the general abundance of manatees in the area. Instead, they were thought to measure occurrence and abundance within small areas to correlate them with habitat features. However, our flights covered areas surveyed in past studies and included new characteristics: (a) areas farthest from the coastline, and (b) three to five flights within specific sampling periods to have a measure of variability. Despite some limitations, these data serve to explore the differences in density among areas with different depth and distance to shore, and to document the variability in counts recorded in distribution surveys.

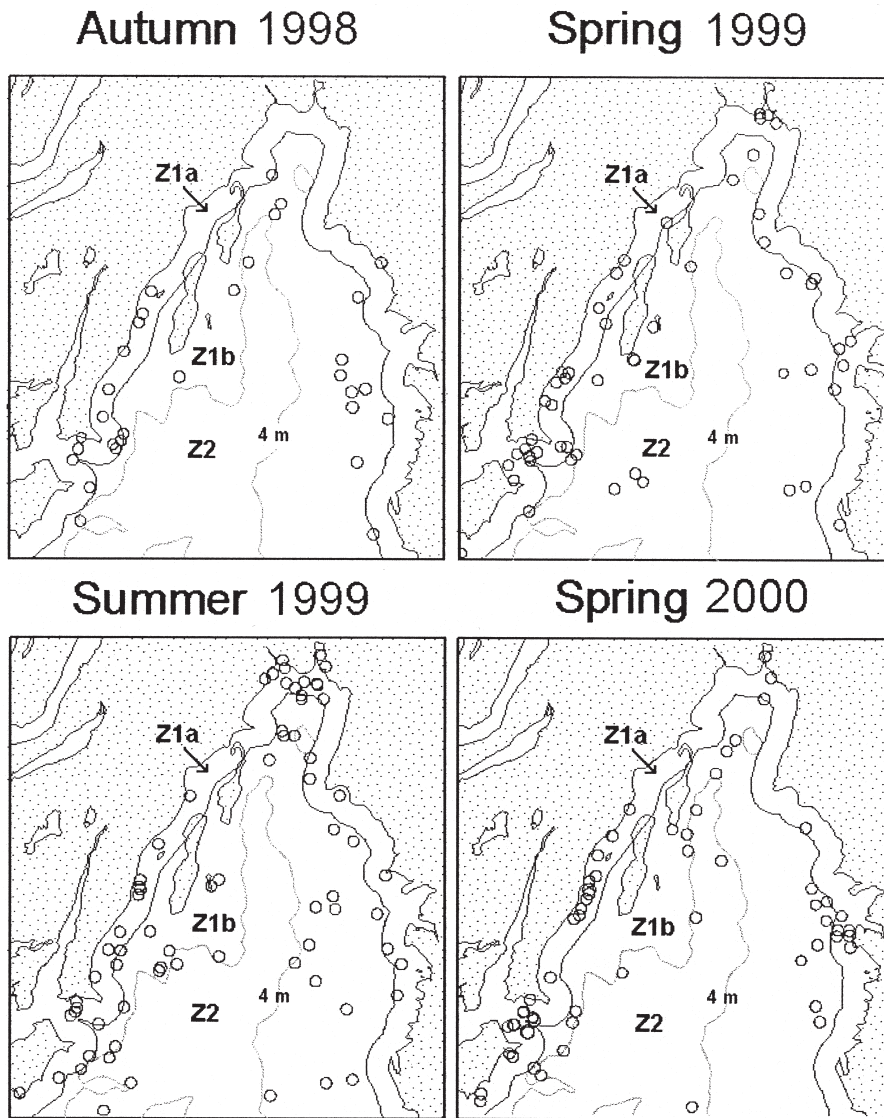We potentially had two major sources of variation: variability due to changes in the actual

Figure 3. Sightings, consisting of one or more manatees located close together (up to 50 m), recorded through aerial surveys conducted on four sampling seasons in northern section of Bahia de Chetumal, Mexico.

number of manatees occupying the general area, and variability due to inexactness of the counts (Link *et al.*, 1994).

The proportion of manatees at or near the surface of the water in shallow zones in our study (42%) was within the 38–47% range observed in turbid waters in Florida (based on telemetry data; Packard *et al.*, 1985), and is comparable with the proportion of dugongs sighted at the surface on sand banks in Moreton Bay, Australia (48%, Marsh & Sinclair, 1989). However, this proportion is

unsuitable as a correction factor, because we cannot assume that manatees use the deeper zones in the same way and have similar breathing behaviour as in the shallow zones. Marsh (1995) used this proportion to correct for counts, but she cautioned that more studies should be done on this subject. We excluded the deep zone from analysis because of our limited survey coverage and because of the high uncertainty associated with counts in this zone.

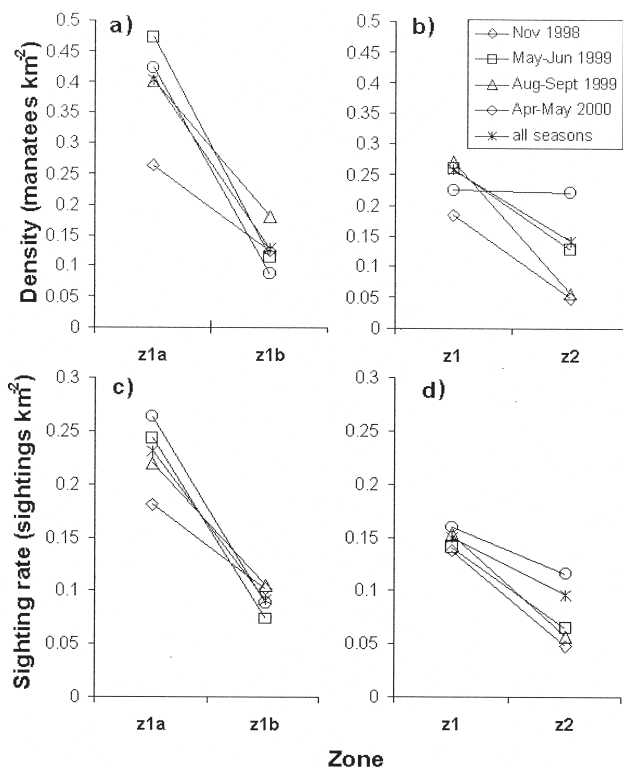Typically, surveys of manatees include only the one km closest to shore. We found that 17 to 33%

Figure 4. Comparison of the mean density (a, b), and sighting rate (b, c), between the shallow zones (z1a and z1b), and between the shallow zones together (z1) and the deep zone (z2), during manatee aerial surveys conducted in the northern section of Bahia de Chetumal. Zone 1a is <4 m deep and <1 km from the shore, zone z1b is <4 m deep and >1 km from the shore, and zone z2 is >4 m deep.

of the manatees in our surveys were beyond this strip (zone 1b in Table 1). If the proportion of manatees expected between the two shallow sub zones were constant among flights, results from the zone nearest to the shore (the one traditionally flown) could be used as a measure of abundance and distribution along segments of the coast. However, the high variation in the proportion of sightings between the two shallow zones precludes this assumption. Use of depth, along with distance to shore, appears to improve manatee surveys, where the shallow area extends beyond 1 km from the shore. Regardless, the use of deeper areas should be studied in more detail.

The 0.115 manatees per km^2 and 0.075 sightings per km^2 recorded in three surveys of the entire Bahia de Chetumal in October and November of 1990 (Morales-Vela & Olivera-Gómez, 1994), were notably less than the averages in our study (0.240 manatees per km^2 and 0.149 sightings per km^2), although they were similar to values obtained on some of our individual flights. The 1990 values

could have, therefore, underestimated the mean density.

In our study, variability among individual flights within a season (34.2–64.9% for manatees per km^2 and 21.3–51.1% for sightings per km^2, in zones 1a and 1b pooled) was similar to the general variability (46.5 for manatees per km^2 and 33.3 for sightings per km^2, in zones 1a and 1b pooled), indicating a high short-term variance in counts. As in ours, in the few studies in Mexico and Central America that included more than one survey, authors recorded high variability among flights (for example, a CV of 55.8% in Puerto Rico; Powell *et al.*, 1981). Averaging of the mean values per sampling season resulted in an important reduction of the coefficient of variation (15.5% for manatees per km^2 and 7.2% for sightings per km^2, in zones 1a and 1b pooled), and indicated the value of performing multiple flights. We concur with other authors that single flights do not produce reliable indices of manatee density or a good idea of their distribution (e.g., Powell *et al.*, 1981; Packard *et al.*, 1985; Miller *et al.*, 1998).

Two kinds of bias could be involved in the resulted variability: visibility bias and sampling bias (Lefebvre *et al.*, 1995). The first can be subdivided into biases in perception and in availability; the first of which refers to the proportion of individuals visible in the transect but not observed, and, the latter to the proportion of individuals present in the transect but not visible (Lefebvre *et al.* 1995; Marsh & Sinclaire, 1989). Standardized flights and good conditions allow visibility bias to have only a low contribution to variability (Miller *et al.*, 1998). In our study, it is likely that water and bottom conditions in the area, the depth of the zones included in the analysis, the short duration of flights, and the low frequency of sightings, along with the experience of the observers, all minimized visibility bias. Unfortunately, this bias was not evaluated in this study.

Sampling bias, caused by manatees being present in the general area, but not within the transects (Lefebvre *et al.*, 1995) could had contributed more than visibility bias to the overall variability in our study area. In our study, manatees could move freely south of the study area, causing variability in counts. However, the few data gathered with radio-tagged manatees in this area indicate that individuals remain within a general area for long periods (Morales-Vela *et al.*, 1996), a fact observed also in Southern Lagoon, Belize (Powell *et al.*, 2001). Manatees could move also within the general area or to adjacent sites. Most adjacent wetlands are too shallow and although manatees have been observed to enter them, they do so only occasionally and in small number, except in Laguna Guerrero and the channel system connecting with open waters of Chetumal Bay, which are used frequently by manatees (Morales-Vela *et al*, 1996; Axis-Arroyo, 1998; Morales-Vela *et al.*, 2000).

Fixed-width transects perpendicular to shore, as used by Miller *et al.* (1998) and Marsh & Sinclair (1989), could improve the precision of abundance estimates in the area. Wetlands adjacent to the bay need to be surveyed, at the same time, so that movements to those areas can be used to properly interpret data obtained in the bay. Sighting probabilities differ between shallow and deeper areas and correction factors should be used when conducting perpendicular transects (Marsh, 1995). Since, not enough information is available to calculate such correction factors, research on this matter should be carried out. Future surveys should be designed to estimate most of the biases that contribute to inexactness in data they produce.

To reduce errors due to aggregated distributions, transects should be placed closer together in some areas and the area should be stratified to make overall estimates. This; however, means an *a priori* knowledge of the areas that have a consistently high use by manatees.

Surveys of distribution of manatees (Ackerman, 1995) are a common and useful tool, and have been widely used. The relative importance of different areas for manatees has been assigned based largely on counts made on these surveys (Lefebvre *et al.*, 1989). Frequently, the need for covering large areas with scarce funds has limited the number of flights over a particular region, and limited also the extent of surveys to a narrow strip close to the shore, leading to high variability in counts and a possible misconception of distribution.

We emphasize the need to use multiple flights during distribution surveys of manatees. The estimate achieved by using several flights brings a range of density that is more useful to detect the importance of particular segments of the coast to manatees. In addition, depth must be taken into account, along with distance to the shoreline, in designing distribution surveys.

In our study area, lack of differences among seasons suggests that surveys should be conducted when the best flying conditions prevail; that is, based on our results, in the dry season. We also recommend that perpendicular transects be included in future surveys in Chetumal Bay to obtain more precise estimates of abundance. Finally, research on the use of deeper areas by manatees and on their general movements is needed.

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