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Effect of the distribution and density of benthic target organisms on manta tow estimates of their abundance

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Abstract. The perception biases associated with manta tow estimates of the abundance of benthic organisms were investigated using artificial targets, the density, distribution and availability of which could be controlled. The proportion of targets which are counted by a manta-towed observer (sightability) and the precision of the resultant estimates of their abundance decreased as the targets were distributed more widely over a reef slope. The sightability of targets was enhanced when they were arranged at a high density or in relatively large groups of 9–11, or when they were located directly under the manta towed observer rather than at the edges of his visual field. Limiting the search width of a manta towed observer to about 9 m should improve manta tow estimates of target organisms. However, in practice this would be difficult for reef organisms such as *Acanthaster planci* because of the extreme three dimensionality of the reef surface relative to the depth of the water.

Introduction

Manta towing, which is used for rapid underwater surveys of benthic organisms, has a number of inherent and largely unmeasured limitations (Fernandes et al. 1990). This paper describes four experiments which investigated the effects of different observers and the distribution and density of target organisms on the perception bias associated with the technique. Marsh and Sinclair (1989a) pointed out that the visibility bias associated with rapid survey techniques typically consists of both perception bias (which occurs when potentially visible target organisms are missed by observers) and availability bias (which occurs when target organisms are unavailable to observers due to viewing conditions). There was no availability bias in these experiments, as the target organisms were all potentially available to the observers.

Artificial targets, of a size and colour similar to *Acanthaster planci,* were used in lieu of live animals because their density, distribution and availability could be controlled. The study was designed specifically to investigate the perception biases associated with broadscale manta tow surveys of *A. planci*, but the results have general relevance to other benthic surveys, especially in coral reef environments.

Materials and methods

A. planci vary considerably in colour and size making them too difficult to imitate exactly. Targets were constructed from white or yellow plastic ice cream container lids (17 × 17 cm). Their tops were painted brown to simulate the starfish. Weights were attached to the underside of the lids.

Divers arranged the targets in 26 different combinations of densities and distributions along a 120 m long strip transect at a leeward site at Heron Island (23°26′S 151°57′E; Fig. 1). The targets were conspicuously placed and, in all except the clumping experiment, were arranged in a haphazard, rather than strictly random manner. The

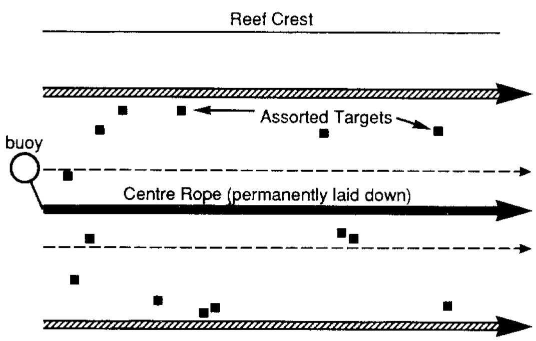

Fig. 1. Diagram of the experimental transect. The 120 m long transect was similar to the distance travelled during a routine manta tow conducted by the AIMS team. The transect was as straight as possible and was permanently marked with surface buoys at both ends and a rope tied to the reef which delineated its centre line. If more than 20 targets were to be moved underwater to effect a new arrangement, two additional ropes were laid down to define the required transect width (hatched lines). In positioning targets, divers mentally divided the transect into thirds lengthwise and set down a third of them in each section (dashed lines). This ensured the distribution of targets throughout the width of transect being investigated

targets were always completely rearranged for each treatment combination so that samples were independent. The manta towed observers did not arrange the targets and the additional ropes used for setting up (Fig. 1) were removed before towing commenced. Transect width was thus defined only by the distribution of targets on the reef.

Time constraints made it impossible to randomise the allocation of treatments completely. The treatment combinations were set up in a logistically convenient but haphazard order with all experiments being conducted concurrently. The observers claimed they were unable to anticipate arrangements.

The targets in each combination were counted by snorkel divers towed along the transect behind a dinghy on individual manta boards at about 5 km h^{-1} ($n=59$, average $=4.80$ km h^{-1}, SD $=0.69$). The manta tow technique was based on that used in routine surveys by the Australian Institute of Marine Science (AIMS) (Bass et al. 1988; Moran et al. 1988). The three observers all had 4–5 years experience as members of the AIMS manta tow team who spend 110–120 days in the field per year. However, unlike the others, Observer 2 had not manta towed for 10 months.

A centre rope guided the observer to the middle of the transect while buoys guided the boat driver along the transect (Fig. 1). On AIMS surveys each area is searched only once until the entire perimeter of a reef is surveyed. However, as it was essential for the observers to be positioned over the targets in this study, each observer was towed in the same direction over each arrangement three times within 15 min (triplicate tow) in order to provide the boat drivers with the opportunity to readjust their steering to allow for the varying amounts of glare, wind, current and tide (which also acted upon the guiding buoys; Fernandes et al. 1990). The count obtained on this third tow was used in all the analyses as driver learning is not a factor in routine surveys.

After each tow, the observer recorded data on a pro forma attached to the manta board. In order to simulate the AIMS manta tow technique as closely as possible, the variables recorded on routine surveys (percentage of cover of live coral, dead coral, soft coral, sand and rubble, and number of feeding scars) were recorded as well as the count of targets.

Experimental design

Width/density experiment. To assess the effect of different densities of targets and different transect widths on sightability, observers were towed over targets distributed over six different widths (3, 6, 9, 15, 21 and 30 m) and at three different densities ("low density" $=0.01$ targets m^{-2}, "medium density" $=0.04$ $\{n=6$, SD $=3.69\times10^{-4}\}$ and "high density $=0.11$ $\{n=6$, SD $=1.08\times10^{-3}\}$). The deviations around density levels were due to divers inadvertently laying out incorrect numbers of targets. Insufficient targets were available for the required number to be placed over the entire 120 m length of the transect at the high density level for the two widest transects tested. The targets were arranged over a length of 86 m for the 21 m wide transect; 56 m for the 30 m wide transect. However, the observers were towed over the whole 120 m transect as usual. The data for the 30 m wide treatment at this density were discarded as they were anomalous.

High density experiment. An additional "very high density" of targets was counted on the 3 m and 6 m wide transects (0.28 and 0.25 targets m^{-2} respectively).

Location experiment. Targets were arranged within a 3 m wide strip on three different parts of the transect: (1) reef crest – between 12 and 15 m above the centre line; (2) middle of reef – 1.5 m on either side of the centre line; and (3) bottom of reef slope – between 12 and 15 m below the centre line. The density of targets (0.22 targets m^{-2}, $n=3$, SD $=1.60\times10^{-3}$) remained constant and was high to maximise the opportunity for detection.

Clumping experiment. The effect of clumping on the proportion of targets counted was investigated using groups of targets of three different sizes: (1) an ungrouped haphazard arrangement as described above; (2) 4–6 targets per clump; (3) 9–11 targets per clump. Targets were arranged within clumps so that their sides were adjacent or overlapping to simulate aggregations of *A. planci*. The width of transect (9 m) and density of targets (0.11 targets m^{-2}) were constant throughout the experiment.

All densities used, except the high density level, have been recorded in natural populations of *A. planci* (Fernandes, unpublished).

Analysis

Sightability was the dependent variable in all the analyses and was defined as the proportion of targets which are counted by a manta towed observer. Logarithmic transformations reduced the heteroscedasticity of the data more successfully than an arc sine transformation and were used throughout. The data were analyzed using forward stepwise multiple linear regressions (Snedecor and Cochran 1980) which maximised r^2 at each stage and used an F-to-enter value of 4. The independent variables entered into each analysis included width and density (in the width/density and high density experiments), location of transect (location experiment), degree of clumping (clumping experiment), and observer (all experiments). Observer was included in the regression analysis as a dummy variable (Zar 1984).

Validation of the methods

Evaluation of possible non-treatment effects

Non-random allocation of treatments. If the non-random order in which different arrangements of targets were placed had enabled observers to anticipate a pattern, a strong positive correlation (Pearson's) might have been expected between the proportion of targets counted and either time of day ($n=63$, $r=-0.261$, $p=0.0387$) or day of field trip ($n=63$, $r=0.159$, $p=0.2140$). This was clearly not the case although one relationship showed a significant negative correlation.

Non-experimental parameters. Wind ($n=63$, $r_s=0.566$, $p<0.0001$) and sun conditions ($n=63$, $r_s=-0.458$, $p=<0.0002$) were the only variables which were highly correlated with sightability (that is, Spearman's $r_s>0.300$) (for list of all variables recorded see Fernandes 1990). The positive correlation of sightability with wind is counter-intuitive and probably arose by chance. The boats were steered into the sun on seven occasions; five of these coincided with five of the 11 experimental arrangements which were expected to result in low proportions of targets being counted (15–30 m wide transects or targets located at the reef edges only). Thus there was little reason to suspect that the results of the experiments had been systematically biased by nontreatment effects.

Results

Effect of transect width

Sightability tended to decrease with increasing width of transect (regression ANOVA: $df=1$, F $=45.03$, P $=0.0001$, $n=42$; Table 1, Fig. 2). A limited number of replicates suggested that the most precise results were obtained using a 9 m wide transect (Table 2). Indeed, if the same density of targets were randomly distributed over a 30 m wide reef slope, the total number counted would, on average, be more on a 9 m wide transect than on a 30 m wide transect (despite less reef and therefore fewer targets being potentially available in a 9 m wide strip). The coef-

Table 1. Factors which significantly affected sightability in the width/density, high density, location and clumping experiments. Results of multiple stepwise regression analyses

Variable	Parameter estimate	SE	Sum of squares	F	P
Width/density experiment				$r^2=0.5296$	
Intercept	1.8202	0.0673	41.1375	731.01	0.0001
Width	−0.0300	0.0045	2.5339	45.03	0.0001
High density experiment				$r^2=0.5584$	
Intercept	1.8934	0.1335	4.3705	201.07	0.0001
Width	−0.0848	0.0226	0.3064	14.10	0.0017
Density	0.0744	0.0310	0.1252	5.76	0.0289
Location experiment				$r^2=0.8070$	
Intercept	−6.5887	1.4835	6.8544	19.73	0.0044
Location	7.8940	1.6846	7.6304	21.96	0.0034
Location^2	−1.8281	0.4168	6.6839	19.23	0.0046
Clumping experiment				$r^2=0.8064$	
Intercept	1.3687	0.0923	2.1409	219.66	0.0001
Degree of clumping	0.1858	0.0451	0.1656	16.99	0.0092
Observer 2	−0.1783	0.0727	0.0587	6.02	0.0577

Table 2. The effect of the width over which the targets were distributed on their sightability. Four randomly chosen data points were used to determine the precision of the estimate of sightability for each transect width to enable comparisons

Width (m)	Precision $n=4$	Sightability		
		Mean	n	95% C.I.
3	0.141	0.654	7	0.488–0.821
6	0.163	0.365	7	0.226–0.504
9	0.122	0.449	9	0.343–0.555
15	0.272	0.209	8	0.140–0.278
21	0.256	0.192	7	0.077–0.307
30	0.356	0.112	4	0.000–0.239
Infinite[a]	0.272	0.148	28	0.093–0.203

[a] Unpublished data from P. Moran

Table 3. Comparison of accuracy and variation of counts estimated over transects of different width

Width	Percentage of targets counted of total on reef slope	Co-efficient of variation
9 m	13.5% ($n=9$)	0.242 ($n=4$)
30 m	11.2% ($n=4$)	0.701 ($n=4$)

ficient of variation (standard error/mean) would also be less (Table 3).

A defined search width of about 9 m should maximise information retrieval. Although the sightability was high on 3 m wide transects, only a small area of reef, which may not be representative, is sampled. As the bias and precision were similar for 6 m and 9 m wide transects, the latter is preferable as it allows a larger area of reef to be sampled (Table 2). Transect widths greater than 9 m give substantially less precise and more biased estimates.

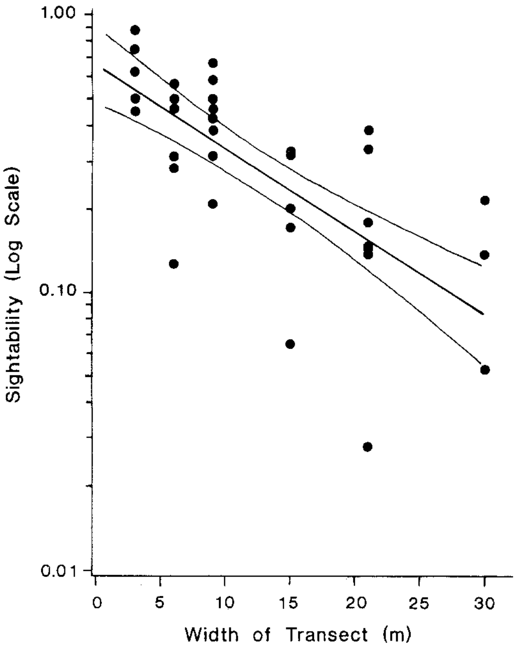

Fig. 2. Effect of the width over which the targets were distributed on a reef slope on their sightability to manta towed observers. Sightability = 1.82 − 0.03(width)

Effect of density of targets

The proportion of targets counted at the three lower densities showed no significant trend in the width/density experiment. However, for all observers, a higher proportion of targets was counted at the "very high density" level (Table 1, Fig. 3; regression ANOVA: $df=2$, $F=10.12$, $P=0.0014$, $n=19$).

Effect of location of targets

None of the observers saw any targets when the targets were limited to the reef crest. When targets were restricted to the bottom of the reef slope, two observers realised where they were after one tow and thus counted more than the other, less experienced, observer who did not locate them at all (Table 1). This marked difference between observers explains the wide confidence limits associated with this regression (Fig. 4; regression ANOVA: $df=2$, $F=12.54$, $P=0.0072$, $n=9$).

Effect of degree of clumping of targets

Groups of 9–11 targets were significantly more sightable than smaller groups. Observers 1 and 3 saw a greater proportion of targets than Observer 2 when the targets were arranged in clumps of six or fewer, but there was no difference between observers for clumps of 9–11 (Table 1, Fig. 5; regression ANOVA: $df=2$, $F=10.41$, $P=0.0165$, $n=8$).

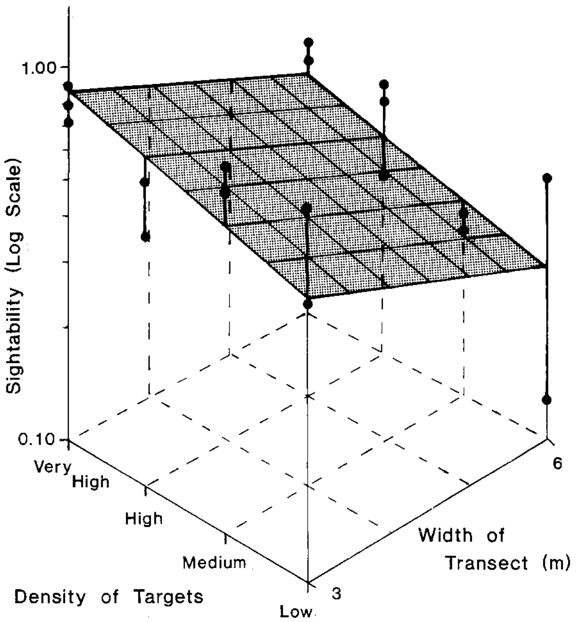

Fig. 3. Effect of the density of targets and the width of their distribution on a reef slope on their sightability to manta towed observers. Sightability $=1.89-0.08$ (width) $+0.07$ (density). Dots represent data points

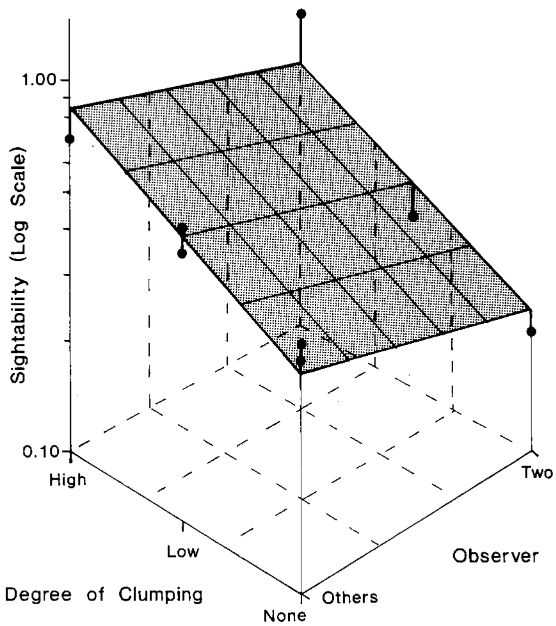

Fig. 5. Effect of (1) the degree of clumping of targets on a reef slope and (2) different observers on the sightability of targets to manta towed observers. Sightability $=1.37+0.19$ (degree of clumping) -0.18 (observer 2). Dots represent data points

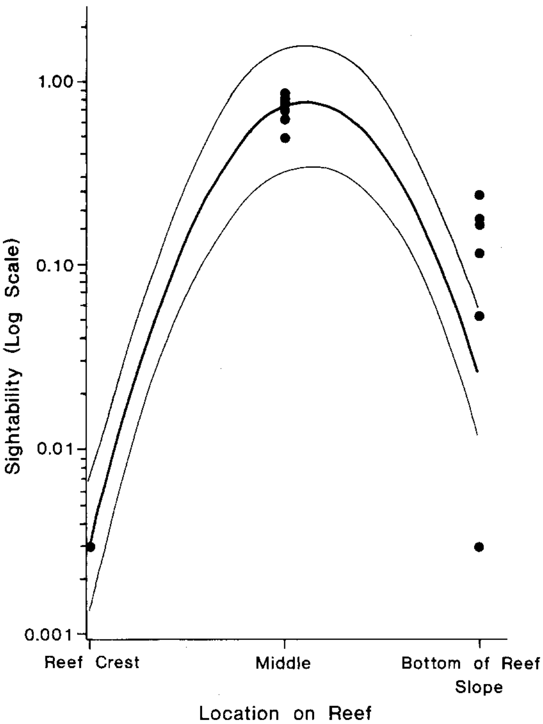

Fig. 4. Effect of the location of targets on a reef slope on their sightability to manta towed observers. Sightability $=-6.59+7.89$ (location) -1.83 (location^2)

Discussion

Target organisms are most seriously undercounted when manta towed observers scan over a whole reef slope. Artificial targets were less sightable and less repeatably counted when arranged over a 30 m wide strip of reef than over any of the narrower widths sampled. The results for targets arranged over 30 m are similar to those recorded for *A. planci* (including cryptic animals) by AIMS manta towed observers searching to the horizon of their visual field (Table 2). The negative relationship between transect width and sightability of the target organism is well documented for aerial surveys, another rapid surveillance technique (Caughley 1974; Caughley et al. 1976; Bayliss 1986; Marsh and Sinclair 1989b). These results suggest that the practice of manta towed observers scanning the entire reef slope would tend to *maximise* the bias (that is, minimise sightability) and *minimise* the precision of estimates of abundance of *A. planci.*

Although this study suggests that a search width of about 9 m should be adopted by observers on manta tow, this is not practicable. The extreme three dimensionality of the reef surfaces presented to observers means that the reef can only be surveyed at a constant width by laying a transect directly on the reef. This would be so slow that it would defeat the purpose of using the manta tow technique. Other methods of limiting search width (for example, delimiting the transect width by marks on the manta board) would not demarcate a constant transect width in a reef environment (Fig. 6). Despite this, using variable search limits is likely to give better estimates than no limits as it may encourage the standardization of search effort, particularly with less experienced observers. Research into the feasibility and effectiveness of limiting search width is required.

The effect of the width over which the targets were arranged on their sightability (Fig. 2) suggests that the area searched by observers was influenced by the location of the targets. This has major implications for surveys in which observers are required to report on several param-

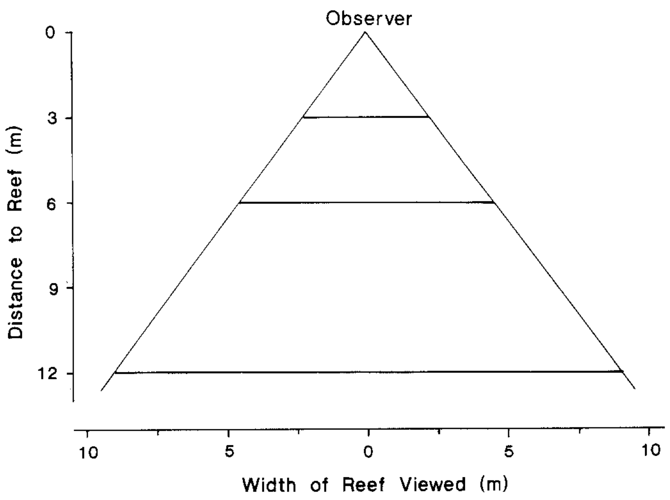

Fig. 6. When a manta towed observer is required to count target organisms in a coral reef environment the extreme three dimensionality of the substrate relative to the depth of the water results in the distance between the observer and the substrate being very variable. As illustrated by this figure, this variability means that using guide markers on manta boards to delimit the transect width will not standardise the width of substrate searched

eters simultaneously. For example, if an observer is asked primarily to count starfish and secondarily to estimate live coral cover on the same manta tow (as is routinely done on the AIMS surveys), it is likely that the observations of coral cover will be biased to those parts of the reef where starfish are sighted. The reliability of observations of multiple parameters should be tested.

The location of targets on the reef slope also affected their sightability. This result is probably attributable to both the effects of peripheral vision and reef topography. If the target organisms are restricted to the edges of a reef slope they could be missed on a normal manta tow which takes the observer over the middle of the slope. If the organisms are noticed, their sightability will probably be extremely low. For some organisms, such as *A. planci* other indices, for example feeding scars, may be available to help observers locate the animals and mitigate this bias.

Although sightability increased at the highest density level, it did not vary over a range of lower densities. As Marsh and Sinclair (1989b) suggested, it is possible that a lower proportion of target organisms were counted at lower densities because observers are less interested and less alert.

The perception bias was lower for groups of 9 to 11 targets than for smaller groups. Samuel and Pollock (1981), Samuel et al. (1987) and Graham and Bell (1989) have observed a similar relationship between group size and sightability in aerial surveys. The effect of group size on sightability was greater for larger groups, a result consistent with that of Marsh and Sinclair (1989b) for aerial surveys of aquatic wildlife. The results suggest that if target organisms are highly aggregated, their abundance could be more accurately estimated than when they are randomly arranged. Unfortunately, the impact of the density and aggregation of *A. planci* on their sightability is still equivocal due to the unavoidable confounding of starfish density with reef zone at the small number of sites sampled by Fernandes et al. (1990).

The effects of the distribution and density of target organisms on manta tow estimates of their abundance can be extremely important and should be investigated empirically for different target species before this technique is used.

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