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Manta tow counts as indices of the distribution and abundance of *Acanthaster planci*: a reply to De'ath

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The manta tow is the established method of surveying the broadscale distribution of outbreaks of crown-of-thorns starfish (*Acanthaster planci*) on the Great Barrier Reef (Moran et al. 1988). Given the widespread application of the procedure and the controversy surrounding its use, we investigated the biases associated with manta tow counts of crown-of-thorns starfish (Fernandes et al. 1990).

Our investigation involved comparing counts of *A. planci* in replicate 200 m × 20 m belt transects obtained by snorkel divers on manta tow with independent counts of the same transects by SCUBA divers. SCUBA counts are less negatively biased than manta tow counts but they also underestimate starfish abundance (Fernandes et al. 1990). In addition, there is an unknown proportion of adult starfish which are unavailable to divers (Fernandes et al. 1990). Work by Zann and Weaver (1988) suggests that this proportion is likely to be large.

The effects of 33 variables describing survey and site conditions on the proportion of starfish seen on SCUBA swims which were counted during manta tows of the same area (Fernandes et al. 1990) were investigated using multiple regression. This proportion (termed sightability) was the response variable in the analyses. De'ath (1992) correctly points out that sightability will change with the density of the starfish unless the relationship between counts of *A. planci* made by SCUBA divers and manta-towed observers is linear and passes through the origin. De'ath (1992) suggests that the variability in sightability which we observed could be due to changes in density of the starfish rather than in the variables which we identified using multiple regression. He concludes that our approach may be inappropriate for assessing biases associated with manta tow counts. We have since expanded our data set ($n=131$ rather than 69 transects) providing an opportunity to evaluate these claims.

As we deliberately worked in areas where the starfish were obvious, it is necessary to extrapolate beyond the range of our data to predict whether the linear relationship between SCUBA counts (response) and manta tow counts passes through the origin. When we calculate this regression for our expanded data set ($n=131$), the 95% confidence interval for the intercept is 6.94 ± 6.03 suggesting that density may have some influence on sightability.

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Table 1. Variables which explained a significant amount of the variation in the sightability of *A. planci* identified by multiple stepwise regression between the square root of sightability (response) and the variables measured by Fernandes et al. (1990). Variables that might be confounded with density such as reef and site have been omitted

Variable	Parameter estimate	SE	F	*P*
Intercept	0.4085	0.0362	127.23	0.0001
Proportion of cryptic starfish	−0.3704	0.0488	57.50	0.0001
Even sloping topography	0.1418	0.0208	46.43	0.0001
Underwater visibility	0.0764	0.0134	32.44	0.0001
Staghorn thickets	0.3762	0.0738	25.97	0.0001
Observer 8	0.1649	0.0372	19.64	0.0001

However, as stated in Fernandes et al. (1990), we included the density and degree of aggregation of the starfish as independent variables in the multiple regressions used to identify variables which explained the variation in sightability. Density and degree of aggregation were not identified as significant.

We pointed out that this may have resulted from density being confounded with other site-specific variables. For example, "very high densities" were recorded on one windward reef site only. We have now recalculated the regressions using the expanded data set, omitting any site descriptor variables that might be confounded with density but still including density and degree of aggregation as independent variables in the analysis. The result is the same as for the smaller data set: over the range of starfish

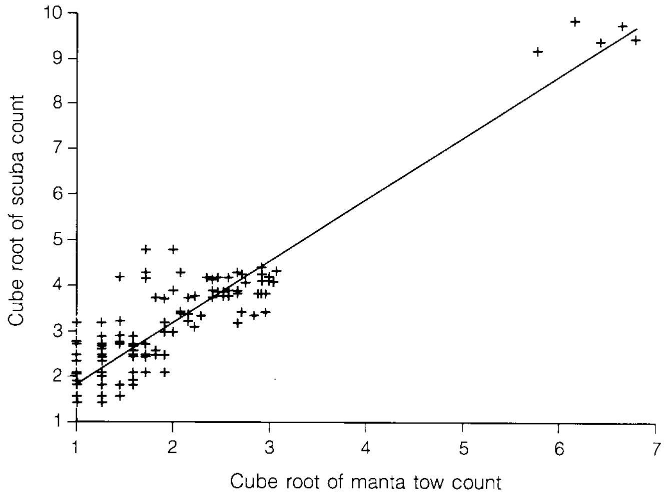

Fig. 1. Survey data showing the relationship between transformed manta tow counts and transformed SCUBA counts of crown-of-thorns starfish illustrating the bimodal distribution of densities at which the starfish are encountered on the Great Barrier Reef

Table 2. Details of the regression relationships between the cube root of the SCUBA counts (response) and the cube root of corresponding manta tow counts of *A. planci*. Separate regression equations have been calculated for (1) the entire data set illustrated in Fig. 1 and (2) the data set omitting the five cases where the starfish were at very high densities

Data set	All data	High counts omitted
N	131	126
Slope ± s.e.	1.3559 ± 0.0478	1.1757 ± 0.0817
Intercept ± s.e.	0.4707 ± 0.10658	0.7745 ± 0.1541
Adjusted r^2	0.8607	0.6222
Leverage[a]	126 cases < 0.016 5 cases > 0.104	All cases < 0.042
P distance[b]	129 cases > 0.944 2 cases < 0.87 (0.862, 0.783)	All cases > 0.941

[a] A measure of the influence of a value of the independent variable in determining the regression coefficient (Weisberg 1980)
[b] The "pseudo-significance" level of the confidence band associated with Cook's distance, a measure of the influence of a case on the regression coefficient (Weisberg 1980)

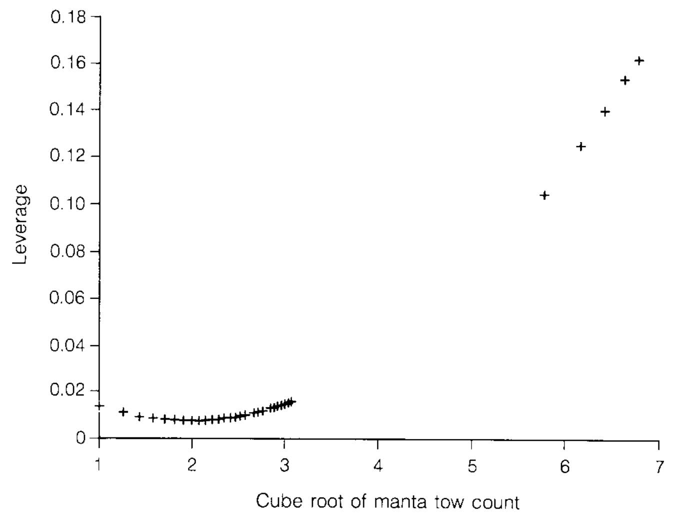

Fig. 2. The influence of each of the cases plotted in Fig. 1 on the regression coefficient

densities for which we have data, the variables which we identify as explaining the changes in sightability are those which make it difficult for a manta-towed observer to see all the starfish which can be counted by a SCUBA diver i.e. water visibility, reef topography and, most importantly, the proportion of starfish that were classified as cryptic by SCUBA divers and which would not have been available to the manta-towed observers (Table 1). This proportion of cryptic starfish is high and variable: mean = 0.39; s.d. = 0.23, range = 0-1, $n = 129$.

De'ath (1992) advocates investigating the effect of these variables on the relationship between SCUBA counts (response) and manta tow counts. We decided against this method in 1990 because the density of *A. planci* tends to be bimodal (Fig. 1) whereas the distribution of sightability is unimodal. De'ath's approach is tantamount to drawing a regression line through two clouds of points; one collected when the starfish were at low densities, the other at high densities when they were outbreaking. De'ath (1992) used the cube roots of both the manta tow counts and SCUBA counts in his regression, but the pattern is not removed (see Fig. 1, De'ath 1992).

When De'ath (1992) regressed the cube root of the scuba counts (SC, response) against the cube root of the corresponding manta tow counts (MTC), he found that the variation in $MTCs^{1/3}$ explained 91% of the variation in $SCs^{1/3}$. The data set on which this analysis was performed comprised 29 pairs of points including four pairs when the starfish were at high densities (see his Fig. 1). We performed a similar analysis on our much larger data set ($n = 131$) which included five cases where the starfish were at very high densities. The variation in $MTCs^{1/3}$ explained 86% (adjusted r^2) of the variation in $SCs^{1/3}$ (Fig. 1). The influence of the high density counts on the overall regression is very high (Fig. 2 and Table 2) and when they are removed, the r^2 is reduced to 62%. The slope estimates changed from 1.356 for the full data set to 1.176 for the reduced data set (Table 2). Indeed the confidence interval for the slope for the reduced data set does not even contain 1.356. When the removal of a few influential points substantially affects the fit of a model, the conclusions from the model are suspect (Draper and Smith 1981). Thus it is unlikely that the linear relationship obtained for all 131 observations is realistic. We are unable to compare statistically the regression equation generated from De'ath's (1992) data with the equations in Table 2 as De'ath does not provide the necessary information.

Neither De'ath's data set nor our data set is appropriate for calculating a regression relationship between scuba counts and manta tow counts over the full range of counts because of the absence of cases where the starfish are at intermediate densities. However, even if it were possible to calibrate manta tow counts to provide accurate estimates of SCUBA counts of *A. planci*, it is unclear to us how this information would enable data collected during broadscale surveys to be used to estimate the absolute number of *A. planci* on a reef (the unit of interest, De'ath 1992).

The area searched by manta-towed observers on broadscale surveys is an undefined and arbitrarily chosen sub-sample of the perimeter of a reef which commonly has a 50–100 m wide band of coral stretching for kilometers (Reichelt et al. 1989). This is a cost-effective method of sampling a wide swath of reef but is not appropriate if an accurate estimate of the number of *A. planci* on a reef is required. In the latter case, it would be necessary to sample all the habitats on the reef either randomly or systematically. Most of the logistical advantages of the manta tow over the SCUBA search would then be lost. In addition, the disadvantages of the manta tow technique would become more important: it is often impracticable to manta tow over much of a reef flat or to sample substrate in water deeper than about 20 m even in conditions of excellent visibility.

A manta tow count of *A. planci* is an index of its abundance within the path of a manta tow which, in turn, is an index of the number of starfish on a reef. The same is true of a SCUBA count estimated from a manta tow count. Given the variable proportion of cryptic starfish and the problems of survey design outlined above, we are not convinced that using manta tow counts to estimate SCUBA counts will provide additional information of value to managers and scientists interested in the status of *A. planci* populations on the Great Barrier Reef.

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