Comparative Study of Three Transect Methods to Assess Coral Cover, Richness and Diversity

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Key words: transect methods, coral cover

Abstract—Three different transect methods were compared at two different sites in Kenya, on their efficiency to estimate hard coral cover, genus richness and Shannon diversity index. For a modified line transect method (LTM), the line intercept method (LIT) and a linear point intercept (LPI) method the relative efficiency of the three methods was calculated with respect to the tested parameters.

   The three methods were examined along identical transect lines (10 m) and a total of 27 transect triplets were recorded in Vipingo and 21 in Mombasa. The correlation coefficients for all three ecological parameters were calculated for the three possible pairs of methods, and the accumulation curves plotted for each of the parameters using number of transects as the independent variable. Results from the three methods were virtually indistinguishable. When the parameters were plotted using measuring time on the x axis, the curves for the LPI method converged twice as fast as those for LTM, while LIT time was intermediate. It is suggested that the LPI method might be most suitable for assessing coral cover, richness and diversity where time and effort are significant constraints.

INTRODUCTION

Studies at all scales of time and space are necessary to understand the mechanisms that determine the dynamics of coral reefs (Connell *et al.* 1997). Sound management requires monitoring of reefs to allow assessment of their present state, 'health' and threats, and how these change over time. A variety of survey methods have been applied by ecologists to monitor coral reef sessile benthic communities in an effort to develop high quality conservation and management strategies. Each of these methods has different advantages and limitations. The purpose of this study was to determine the most efficient line transect method.

   The community structure can be described both quantitatively and qualitatively (e.g. Dartnall and Jones 1986; English *et al.* 1994; Mumby *et al.*

1995). The census techniques compared in this study are intended to gather quantitative information. Most commonly used quantitative census methods in coral reef surveys are modifications of transect or quadrat methods originally used in plant ecology surveys (see e.g. Loya 1972, 1978; Kinzie and Snider 1978). Until now only few comparative studies have been carried out with the purpose of evaluating quadrat and transect methods applicable for reef community surveys (Kinzie and Snider 1978; Weinberg 1981; Dodge *et al.* 1982; Birkeland 1984; Olhorst *et al.* 1988; Uychiaoco *et al.* 1992).

   Transect methods are often preferred over quadrats for coral reef community studies and are widely used to assess environmental impact, whether human-induced or natural. Quadrats are more suited to fine-scale surveys with specific

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questions, whereas transects are suited to medium-scale surveys with more general questions asked e.g. what is the coral cover of our reefs and how is this changing? Transect methods tend to be quicker than quadrats to apply, are less sensitive to small-scale spatial variation, and when sampled in sufficient number do not give less information concerning cover (Kinzie and Snider 1978). Quadrat methods, such as those proposed by Weinberg (1981), are more laborious to apply, are more sensitive to human error concerning estimation and are difficult to place in a highly three-dimensional structure (Olhorst et al. 1988). Following the above assessments of transect versus quadrat methods, and specifically the findings of Loya (1972) and Olhorst et al. (1988), we opted to concentrate exclusively on transect methods.

Time is limited in marine fieldwork with diving/snorkelling constraints coupled with fatigue and cold affecting survey time and with intertidal studies limited by tides. In addition, if SCUBA-diving is needed for the study air reserves and depth limited bottom time become factors (Jones 1971; Olhorst et al. 1988). Some methods, such as photo and video monitoring techniques, give more field information in the same overall time necessary to perform a reliable estimate of the three parameters tested by us, but often these methods need considerably higher analysis time and technical or computer equipment in the field and laboratory (see e.g. Weinberg 1981; Uychiaoco et al. 1992).

The methods compared in this study were a modified line transect method (LTM: McClanahan and Shaffir 1990; McClanahan pers. comm.), the line intercept method (LIT: Loya 1972) and the linear point intercept method (LPI: Obura, 1995). Each of these is described in detail below. The objective of this survey was to compare these three transect methods for three ecological parameters commonly reported in coral reef studies: hard coral cover, genera richness and diversity (Shannon-Wiener). The results of the three methods were compared and evaluated between two sites. The possible influence on the outcome due to differences in coral reef complexity and diversity was investigated. Also the efficiency, including time, operator experience, and parallax problems of each method in estimating the parameters considered was evaluated.

MATERIALS AND METHODS

The study was conducted over a period of five months (November 1997-March 1998). The study sites were chosen on the basis of previous research (e.g. McClanahan and Shaffir 1990; McClanahan 1994, 1997), their accessibility and their apparent differences in diversity and habitat complexity. The first site was situated at Vipingo (03°47' S and 39°51'E), about 30 km north of Mombasa. The reef is unprotected, has a relative low complexity and is adjacent to the sandy beach. The second site was Mombasa Marine Park (MMP; 03°59'S and 39°45'E), gazetted as a park since 1986, but only enforced in the early 1990's (M.S. Omar pers. comm.) and considered having a relatively complex topographical structure. The study was performed on lagoon patch reefs of both study sites, and during the spring low tides.

The starting point of the transect was chosen at random and its direction was laid parallel to the current, to avoid the line being swept sideways during recordings. A set of the three methods, termed a triplet, was performed on each transect: modified line transect method (LTM, McClanahan and Shaffir 1990; McClanahan pers. comm.), line intercept method (LIT, Loya 1972) and linear point intercept method (LPI, Obura 1995). The sequence in which each of the three methods was applied within a triplet was randomised. On each sampling day, two triplets were completed, separated by at least 10 m. In order to minimise observer bias, all methods were tested by the same observer (NB) using the same recorder (EVB).

The optimal length of transect lines is dependent on several factors and is a matter of discussion (Licuanan and Montebon 1991). In order to retrieve an unbiased estimate of cover, the length of the transect line should be long with in respect to the individual coral head or colony occurring and short in comparison to the total sample site (Lucas and Seber 1977). A 10 m transect line was chosen because it has proven to be an adequate sample size for a quantitative study of hermatypic corals in different reefs investigated (see Loya 1972, 1978). It is also the commonly used length by Kenyan coral reef researchers (McClanahan and Shaffir 1990, Obura 1995) and a convenient length to handle in the field.

The transect line was a flexible measuring tape, marked in millimetres, which was stretched horizontally over the seabed. Lead weights at both ends were used to straighten the line. In many studies, the line is only loosely draped over the seabed (Loya 1972; McClanahan and Shaffir 1990), but to enable effective comparison in the present study, the line was kept taut for all three methods. The methodology used for each method was as follows:

Linear Point Intercept (LPI, Obura 1995, and see also Loya 1972 for detailed description): the line is marked every 10 cm, and sessile benthic organisms or substrate category directly beneath the marks were recorded. To allow comparison with the two other methods every object was given an artificial 'length' of 10 cm.

Modified Line Transect (LTM, McClanahan and Shaffir 1990; McClanahan pers. comm.): using a tailor's tape measure (1.50 m length with divisions in centimetres and millimetres) the exact 'contour' length of each substrate category or coral beneath the 10 m line was measured to the nearest centimetre. This method gives a cumulative transect length that will be greater than the 10 m transect length, and is used for calculation of percent cover for each cover category.

Line Intercept Transect (LIT): the 'projected' length of each substrate category or coral beneath the 10 m line was recorded to the nearest centimetre (Loya 1972; English *et al.* 1994). A taut tailor's tape was held directly above the substrate, beneath the 10 m line, to minimise parallax errors that would result from simply reading off the 10 m line. The projected length is shorter than the contour length from the LTM method.

All sessile benthic organisms, and substrate types, were recorded for the three different methods. A common set of cover categories were used for all methods and are listed in Table 1. Corals, algae and other benthic sessile taxa were identified to genus level, but ultimately grouped into the following broader categories: algae, hard coral, soft coral, sponge, substrate and giant clam. Veron (1986) and Richmond (1997) were used as references for identification. Where a coral colony included both dead and living tissue, the dead tissue was recorded as 'substrate' and the living tissue

was identified to genus. This paper focuses on the hard coral data generated by the comparison, with analyses of hard coral genera coverage, genus richness and diversity.

The time needed to perform each census method was recorded individually, and hereafter called 'census time'. The time needed to put the transect line in place was recorded ten times and an average of that time was calculated. This time is called the 'overhead time'. The sum of the average overhead time, and the individually measured census time are called the 'overall time'.

In order to determine whether enough transect line had been recorded an objective criterion for 'convergence' is needed. The more transects that have been measured, the less influence adding a new transect should have on the estimate of any of the parameters. The following criterion for convergence was used, a doubling of the length yields less than 10% change.

In the study, methods were tested for the following ecological parameters: percentage cover of hard coral, coral genus richness and diversity. The relative coral cover was calculated by dividing the recorded length of each coral genus by the total length of transect. Total length, for both LIT and LTM, were taken as the sum of the lengths of all the substrate categories under the transect. As described above, each 'point' of an LPI transect was equated to 10 cm, resulting in a total transect length of exactly 10 m. The richness was calculated as the number of hard coral genera present under the transect line. The Shannon diversity index was calculated on the length of the hard coral genera.

RESULTS

A total of 27 triplets surveys were undertaken at the Vipingo reef and 21 in the MMP. The coral genera and other substrate categories recorded and their occurrence at the two sites are listed in Table 1. For each of the three variables considered, our criterion of convergence was matched (see Fig 1). For example, in MMP after 20 transects 22 genera were recorded with the LTM method. After 10 transects we had a total of 20 genera with the same method. So doubling the number of transects resulted only in a 10 % increase in genera recorded.

Table 1. Substrate cover categories for Mombasa Marine Park (MMP) and Vipingo: Average number of records per transect for each of the coral genera/categories, for MMP and Vipingo respectively; data for three methods pooled. LPI, LIT and LTM: coral genera or other category recorded by each method; data for the two sites pooled

Genera	MMP	Vipingo	LPI	LIT	LTM
Corals Acanthastrea	0.108	0.000		+	
Acropora	1.477	0.185	+	+	+
Alveopora	0.169	0.086	+	+	+
Astreopora	0.215	0.111	+	+	+
Echinopora	0.354	0.000	+	+	+
Favia	2.231	0.284	+	+	+
Favites	1.646	0.025	+	+	+
Fungia	0.000	0.123	+	+	+
Galaxea	1.646	0.593	+	+	+
Goniastrea	0.400	0.000	+	+	+
Goniopora	0.415	0.012	+	+	+
Hydnophora	0.323	0.000	+	+	+
Leptastrea	0.231	0.000	+	+	+
Leptoseris	0.046	0.000			+
Millepora	0.154	0.000	+	+	+
Montipora	3.215	0.580	+	+	+
Pavona	0.354	2.123	+	+	+
Platygyra	1.185	0.210	+	+	+
Pocillopora	1.462	0.148	+	+	+
Porites	13.338	4.988	+	+	+
Psammocora	0.123	0.000	+	+	+
Seriatopora	0.000	0.099	+		+
Stylophora	0.000	3.247	+	+	+
Tubipora	0.000	0.432	+	+	+
Turbinaria	0.046	0.000	+	+	+
Other invertebrates					
Soft Coral	3.462	3.494	+	+	+
Giant clam	0.231	0.000	+	+	+
Sponge	0.462	0.617	+	+	+
Algae	3.308	3.494	+	+	+
Seagrass	0.000	1.531	+	+	+
Substrate	21.354	19.321	+	+	+
<Missing>	0.046	0.000	+		+

Hard coral cover

The Vipingo reef has a lower hard coral cover than in reef in the MMP (Table 2). The mean for both sites was lowest for the LIT method and highest for the LTM analysis. For coral cover assessment the three methods were highly correlated for all possible pair-wise combinations (i.e. LIT vs. LTM, LIT vs. LPI, LPI vs. LTM)(Table 3 'correlation') however, the methods produced significantly different values when tested with a paired-sample t-test (table 3, P t-test). The two-way analysis of variance also revealed that the three methods were significantly different (Table 4). None of the interaction terms in the analysis was significant, indicating that the differences between methods are consistent between the two study sites, and hence independent of habitat complexity.

Hard coral genus richness

For coral genus richness, the lowest values were derived from the LPI method and the highest for the LTM at both sites. The pair-wise comparison of methods, using paired-sample t-test, showed all methods to be significantly different, though the
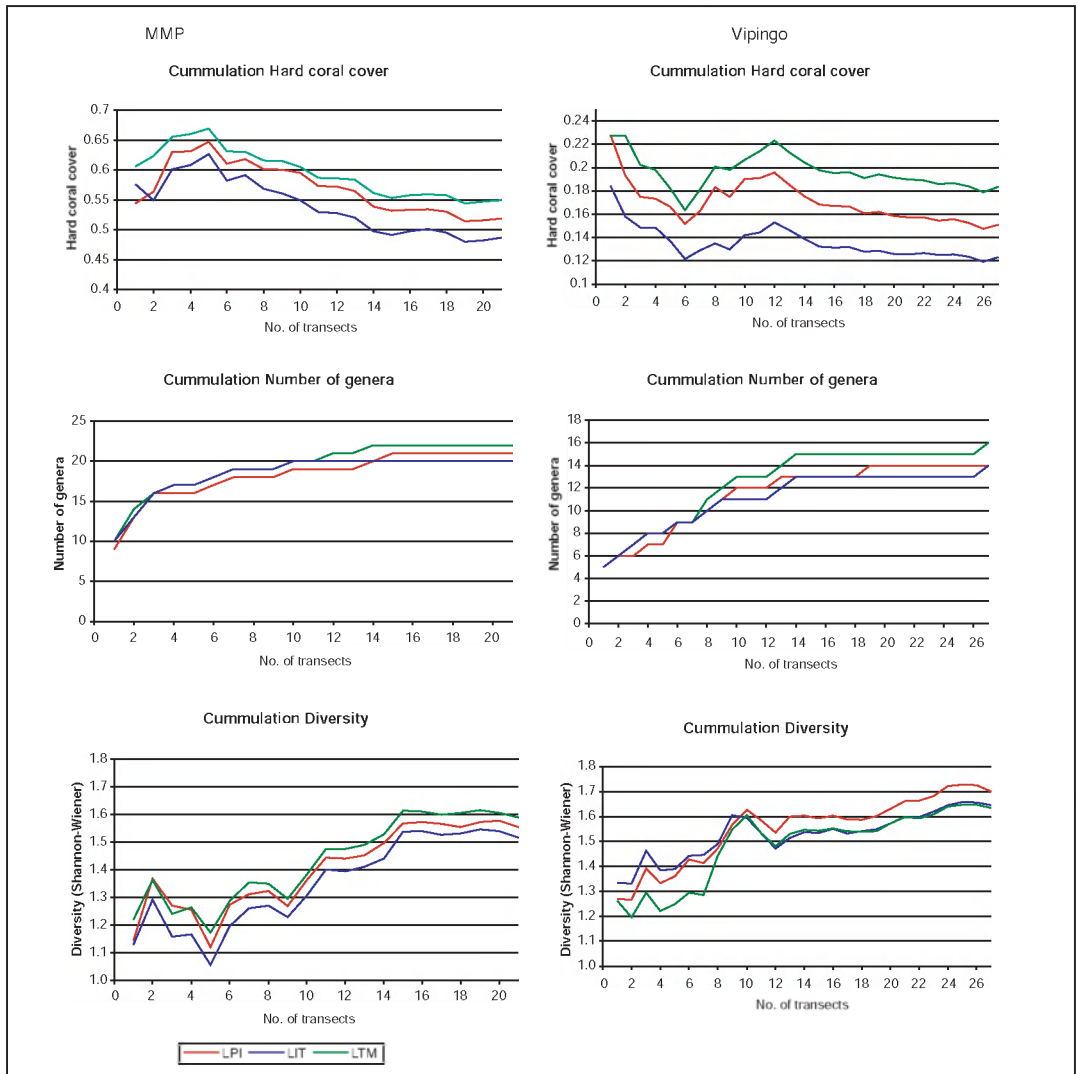
Fig. 1. Accumulation curves for three ecological parameters against the total number of transects, per study site (left MMP and right Vipingo)

p value for the comparison between LPI and LIT was only marginally lower than 0.05 (Table 3). The two-way ANOVA showed marginally non-significant difference between the methods (Table 4). The discrepancy between the tests is an artefact of the tests themselves, because in the two-way ANOVA, transects are pooled within every combination of method and locality before testing, while with the paired-sample t-test, the estimates from each of the three methods are compared within one transect.

Hard coral genus diversity

Coral genus diversity, expressed by the Shannon index, was also highest for the LTM and lowest for the LIT in both sites (Table 2). The correlation coefficient for all pair-wise combinations was high and, as for the other two ecological parameters, lowest between LTM and LPI (Table 3). None of the paired-sample t tests or the two-way ANOVA showed significant differences between the methods (Table 4).

Table 2. Mean and Standard deviation for hard coral cover, richness and diversity for each method at the two sites (n = 21 for MMP, n = 27 for Vipingo, for all rows). StDev = standard deviation

		MMP		Vipingo	
Hard coral cover (%)					
	Method	Mean	StDev	Mean	StDev
	LPI	57.0	4.2	17.0	1.8
	LIT	53.9	4.6	13.5	1.4
	LTM	59.5	4.0	19.6	1.5
Richness					
	LPI	8.047	1.829	4.259	1.583
	LIT	8.333	2.033	4.518	1.396
	LTM	9.142	2.220	4.814	1.594
Diversity					
	LPI	1.272	0.397	1.113	0.379
	LIT	1.252	0.403	1.113	0.394
	LTM	1.300	0.407	1.132	0.381

Table 3. Pairwise comparisons between survey methods. Calculations based on individual transects as data points. Probability is calculated from two-tailed paired-sample t-test

	Comparison	Correlation	P t test
Hard coral cover			
	LPI - LIT	0.99	< 0.001
	LPI - LTM	0.99	< 0.001
	LIT - LTM	0.98	< 0.001
Richness			
	LPI - LIT	0.94	0.041
	LPI - LTM	0.93	< 0.001
	LIT - LTM	0.95	< 0.001
Diversity			
	LPI - LIT	0.93	0.676
	LPI - LTM	0.92	0.326
	LIT - LTM	0.96	0.071
Census time			
	LPI - LIT	0.66	< 0.001
	LPI - LTM	0.67	< 0.001
	LIT - LTM	0.69	< 0.001

Survey census time

The LTM required more than twice the time of the LPI method (mean of 18.1 versus 6.6 minutes respectively, see Table 5, and time needed to conduct the LIT method fluctuated between the other two (mean of 13.8 minutes). The sequence in which the methods were carried out, did not have a great influence on the census time, though there was a slightly decreasing, but non-significant trend

Table 4. Results of two-way ANOVA on the three substrate parameters and the census time

Source	DF	MS	F	p
Hard coral cover (%)				
Location	1	471.500	410.318	< 0.001
Method	2	4.064	3.536	0.032
Interaction	2	0.013	0.011	0.989
Richness				
Location	1	560.519	179.808	< 0.001
Method	2	8.357	2.681	0.072
Interaction	2	1.093	0.351	0.705
Diversity				
Location	1	0.855	5.533	0.020
Method	2	0.014	0.089	0.915
Interaction	2	0.002	0.016	0.984
Census time				
Location	1	150.640	11.494	0.001
Method	2	1,447.934	110.477	< 0.001
Interaction	2	6.203	0.473	0.624

(Table 5). The mean overhead time per transect (i.e. setup time) was 3.33 minutes. Correlation coefficients from comparison of the different methods were again all significant, though lower than for the three ecological parameters (Table 3). The paired-sample t-tests showed that census times were significantly different between methods, as also demonstrated by the two-way ANOVA results (Table 4). The overhead time is not important for the above analysis, since it is a constant for each set of transects.

Accumulation curves were plotted for all parameters against the total number of transects performed per study site (Fig. 1). These curves demonstrate how the three methods closely follow almost exactly the same pattern. In general, the three methods stabilise after approximately 14 - 15 transects. When total overall time is used as the X-axis (Fig. 2), instead of number of transects (Fig 1), the accumulation curves are clearly different, as expected from the difference in time needed to perform each of the three methods.

DISCUSSION

It has been demonstrated that protected reefs have a higher coral cover than unprotected reefs (McClanahan, 1997). As expected, the final values of the three methods differed for the three

Table 5. Mean census time in minutes, by method sequence and site, with the overall mean for all transects. Columns labelled '1', '2', '3' and 'not recorded' refer to the order in which the methods were applied

| Method | Method sequence order | | | | Overall |
	Not recorded	1	2	3	Mean
LPI	7.63	6.89	6.68	6.24	6.64
LIT	17.75	15.06	12.17	13.16	13.77
LTM	20.80	19.56	17.84	15.39	18.12

ecological parameters when Mombasa Marine Park was compared to Vipingo. Because of its less complex coral community, Vipingo was assessed faster than MMP by all three survey methods. The comparison between the three methods gave the same relative results for both sites. Complexity of the habitat did not have an influence on the relative performance of the methods, as demonstrated by the absence of a significant interaction in the ANOVA.
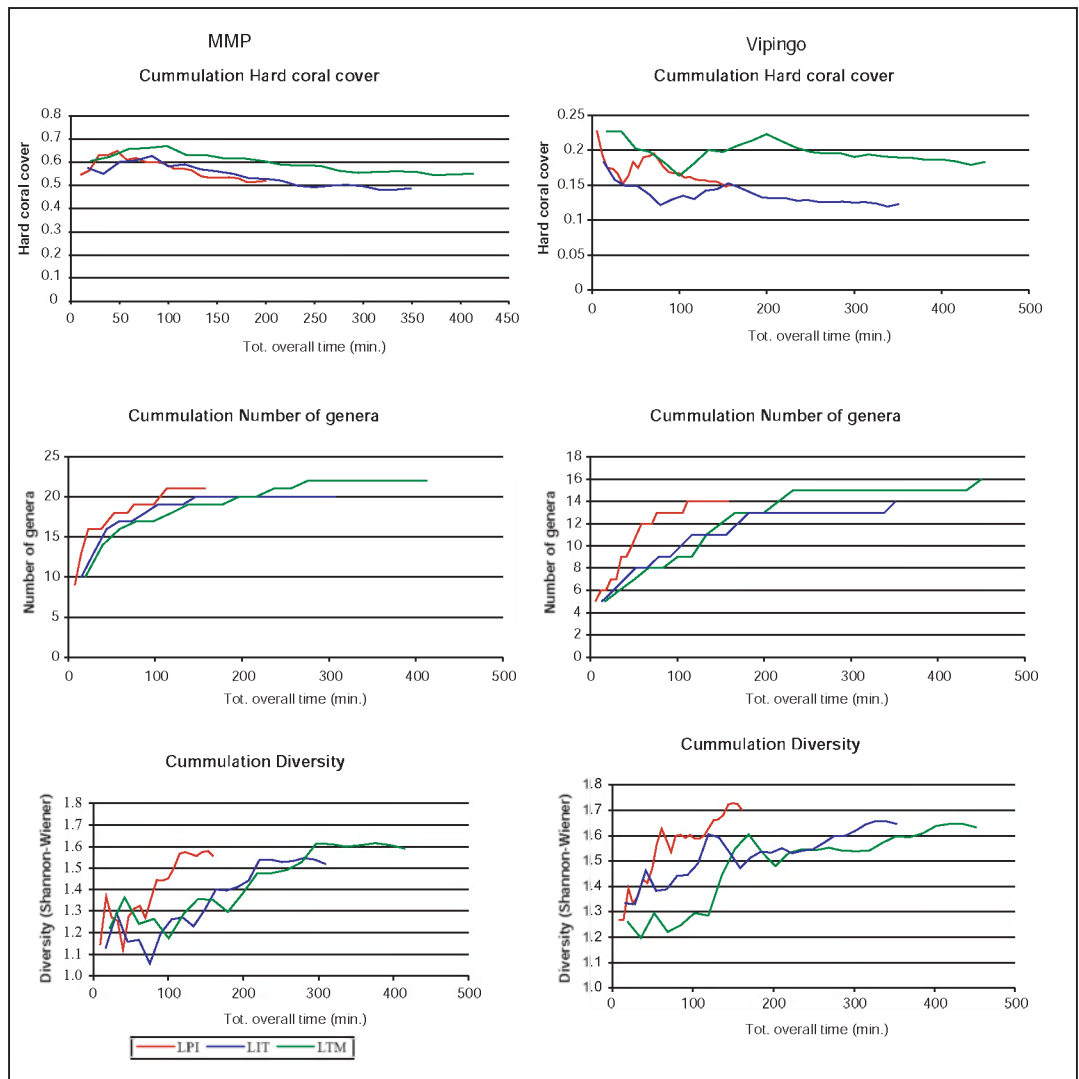

Fig. 2. Accumulation curves for three ecological parameters against the total overhead time (in minutes), per study site (left MMP and right Vipingo)

The three methods yielded approximately the same estimates for coral genus diversity and they were not significantly different. The LPI method however took less than half the time to complete compared to the LTM, thus considering field time limitations, more than twice the number of transects can be performed and therefore, a larger area can be assessed using the LPI. With respect to hard coral cover, the LTM measured a fundamentally different parameter from the other methods. It followed the contours, whereas the LIT is only a projection of the real three-dimensional structure and the LPI actually only records 'points'. However, the pair-wise correlations between the three different methods are very high, therefore it should be possible to devise a conversion factor and calculate one from the other. The study demonstrates how the LTM outperforms the two other methods for the last parameter, coral genus richness. With LTM several cryptic genera were recorded, which were not picked up by the two other methods (see table 1). Nevertheless, again the time efficiency of the LPI method is so much higher that the LPI should be opted for as the field method of choice, and in order to include cryptic coral genera, some modifications could be applied (see below). Based on the present findings and our criterion of convergence 14 to 15 replicates appear to be a sufficient for each site to generate reliable estimates for the parameters tested.

Depending on the monitoring method, time in the field or in the lab, can be a constraint to the acquisition of reliable and useful information. Transect methods should be carefully chosen according to the research questions being asked. From this study, LPI method is the most efficient method for determination of coral cover, genus diversity and genus richness and the time needed to deploy a 10 m line was approximately 3 minutes. The LPI method was also found to be more time-efficient than the LIT method in the study by Dodge et al. (1982). To carry out the LTM two field people are necessary: one observer and one recorder, yet the LIT can be performed by one observer-recorder, however two field people improve efficacy. Although we conducted the LPI method with two field people for comparison reasons, this method can be perfectly applied by one observer/recorder without significant loss of time.

Transect methods have a tendency to overestimate coral density and cover due to parallax problems (Olhorst et al. 1988). All the methods tested by Weinberg (1981) tended to overestimate relative coverage. Based on the findings from the present study for the LIT and LPI methods, overestimation is probably mainly due to parallax, which could be minimised with use of a plumb line. According to Allison (1999), who uses a modified LIT method (with a plumb line), results are more objectivity despite the slightly longer time needed. This modification was not attempted with either of the LIT or LPI methods tested in this study, though a study of the effect of plumb lines would be interesting. The third method, LTM, is not subject to human error from parallax problems, but following contours of branching corals (e.g. certain Acropora sp.), is likely to create variability between observers.

Population densities (colonies/m2) can be calculated from data gathered with the LTM and LIT. By making some assumptions, the measurements made with these two methods can be converted to estimate densities as number of individual colonies per unit area (Lucas and Seber 1977; Marsh et al. 1984). To our knowledge, no such method exists for data collected with the LPI method. Weinberg (1981) converted the thickness of the transect line into 1 cm and considered each 'point' of the LPI method as 1 cm2 to be able to compare the surface area covered by transect methods to the area covered by quadrat methods and thus calculate densities. In our opinion, this sort of conversion is incorrect and irrelevant. The inability to estimate population densities should be considered as a weakness of the LPI.

When researchers decide to use the LPI method for study, our suggestion is that some simple additions are needed to improve the technique. These additions require testing, which were not undertaken in the present study through lack of time. For example, the LPI technique could be supplemented with a belt of 1 m; and every genus of hard coral 0.5 m of either side of the transect line could be recorded. This way the under-represented and cryptic corals will be included, only as presence/absence.

Only three parameters were tested in this study and the presentation only reflects the analysis of

the hard coral data. Other parameters and more taxa, such as algae and other (sponges, soft coral, etc.), benthic cover, richness and diversity can also be examined. LPI apparently could be the fastest method for surveys and assessments e.g. of bleaching and sedimentation. Research questions should determine the choice of the field method used, but we recommend the use of an adapted LPI method when selecting transect methods. For studies over longer time frames, such as recruitment, the more laborious and time consuming quadrat methods are more appropriate.

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