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ABSTRACT

Coral reefs around the world are facing increasing disturbance; however, the ability to monitor them is constrained by cost and experience factors. The Line Intercept Transect (LIT) method is usually used with an expert level of identification (30 benthic categories and sometimes coral genera), but these are time-consuming, require a high level of expertise and are therefore expensive. Over the last 20 years, surveys performed by non-specialist volunteers have provided data for increasing numbers of reefs, using simplified sampling methods and more basic levels of identification. In between these extremes, new stakeholders (e.g. environmental assessment agencies, consultancy firms, marine nature reserves, etc.) requiring an intermediate level of expertise and resolution are now carrying out coral reef surveys. Across all levels, it is desirable to identify monitoring methods that optimize the data provided and the ease of implementation according to the users' needs. In this study on surveys from Réunion Island collected between 2003 and 2013, we used multivariate analyses to compare four increasing levels of identification using the LIT method. For each level, we studied the structure of the benthic community and its spatial (reef flat vs. outer slope) and temporal (before vs. after a cyclone) variation. The most basic level of identification showed differences between the reef flat and outer slope, but did not show a significant effect of the cyclone on the benthic community. The two highest levels of identification, both of which we rated 'expert', showed the highest differences in variation. The intermediate level of identification supplied the same information as the expert levels, but required less effort and was therefore less expensive. Next, we compared the LIT with the Point Intercept Transect (PIT) method. At a level of identification appropriate to the interval used, PIT supplied an almost equivalent level of information as LIT, while reducing the time spent underwater. Thus, when managing coastal areas or carrying out impact studies to monitor disturbance, it may be useful to (i) perform surveys with an intermediate level of identification, and (ii) using PIT rather LIT.

1. Introduction

Coral reefs are currently facing many disturbances (Hodgson, 1999; Wilkinson, 2000, 2008). Studying these disturbances and the resilience of reefs is necessary to understand the possible effects and extent of these threats and to put in place appropriate

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management and conservation measures. The first scientific surveys of coral reefs were carried out more than 40 years ago (Talbot, 1965; Loya, 1972; Risk, 1972), and current methods are largely based on these. However, the evolution of coral reef health is still poorly understood and almost no effective large-scale efforts to mitigate damage have been developed since then (Risk, 1999; Wilkinson, 2008). This may be explained in part by the fact that only a small proportion of the world's reefs are being researched (Hodgson, 1999), combined with a lack of means, as monitoring programs require significant technical, human and financial resources (Hill and Wilkinson, 2004).

Scientific surveys that are carried out on reefs typically use the Line Intercept Transect (LIT) method, described by English et al. (1997) and recommended by the Global Coral Reef Monitoring Network (GCRMN, Hill and Wilkinson, 2004), to describe benthic communities (Souter et al., 2000; Muhando, 2008; Patterson et al., 2008). Many monitoring programs also identify each coral genus in their surveys (Francini-Filho et al., 2013; Tourrand et al., 2013). These kinds of surveys are expensive and time-consuming (Leujak and Ormond, 2007) and usually rely on a limited number of experienced scientists (Hill and Wilkinson, 2004). Moreover, many studies based on these surveys analyze only the percentage cover of coral growth forms (Scopélitis et al., 2009; Patterson et al., 2008) or the impact on selected key taxa in response to a specific issue (Meesters et al., 1996; Hennige et al., 2010).

In the Indian Ocean, some monitoring programs use the LIT method with a reduced number of benthic categories (Rajasuriya, 2008; Kumara et al., 2008). The taxonomic identification of corals and details about non-coral categories are therefore not always included. In addition, since the 1990s, community-based programs with the aim of surveying a greater number of coral reefs, such as Reef Check (Hodgson, 2000), have been increasingly popular. Yet as community-based surveys are performed by non-specialist volunteers using simplified methods with a low level of identification (Hodgson, 1999), such surveys, while indicating broad-scale changes, are incompatible with specific, rigorous scientific goals (Segal and Castro, 2001).

Between these two extremes of monitoring program protocols, from highly detailed data gathering by experienced researchers to broad-scale assessment by non-specialists, a new type of stakeholder has appeared, requiring an intermediate level of expertise and accuracy. Organizations such as environmental assessment agencies, environmental consultancy firms and marine nature reserves are now carrying out coral reef surveys. With the strengthening of legislation requiring environmental impact assessments (Levrel et al., 2012), survey methods that provide an optimal compromise between data gathering and ease of implementation are sought. These stakeholders require a new level of resolution, adapted to their expertise and their marine management or monitoring goals with strong financial constraints.

To date, studies comparing scientific and community-based protocols have focused on the ability of non-specialists to record reliable data (Harding et al., 2000; Gillett et al., 2012). Some surveys were performed by expert users using estimation techniques to seek greater time efficiency for an acceptable resolution of data (Obura and Mangubhai, 2011; Wilson et al., 2009), but previous to our study the ecological information provided by different levels of identification had not been compared and no intermediate level had been statistically tested.

In the aim of simplifying survey effort, several authors have recommended the use of sampling methods that are faster than the LIT, such as the Point Intercept Transect (PIT) method (Dodge et al., 1982; Segal and Castro, 2001; Hill and Wilkinson, 2004), quadrat methods (Clua et al., 2006; Price and Harris, 2009) or point-sampling analysis (Leujak and Ormond, 2007; Dumas et al., 2009). Our study focused on the linear methods (PIT and LIT) currently used on Réunion Island and in a large area of the southwestern Indian Ocean (Chabanet et al., 1997; Obura et al., 2008; Tourrand et al., 2013). The PIT method is easier to implement and has been used in a number of studies (Augustin et al., 1997; Harris and Sheppard, 2008; Harding and Randriamanantsoa, 2008; Adjeroud et al., 2009). Although some studies have compared totally different survey methods, such as quadrats, linear methods or point-sampling analysis methods to assess coral cover (Lam et al., 2006; Nadon and Stirling, 2006; Leujak and Ormond, 2007) or to monitor bioeroding sponges (Schönberg, 2015), or linear methods on their efficiency to estimate coral cover, richness and diversity (Beenaerts and Vanden Berghe, 2005), ours is the first to compare PIT and LIT methods according to the level of identification used.

This study used data collected between 2003 and 2013 around Réunion Island on reefs typical of the Indo-Pacific, where hard coral is the dominant biotic substrate and has high species diversity (Bouchon, 1981). There were three main goals of the study: (i) to compare expert and low levels of identification of the LIT method and to suggest an intermediate level, (ii) to compare LIT and PIT methods and to suggest PIT intervals adapted to each level of identification, and (iii) to recommend the optimum level of identification and method according to cost-effectiveness and objectives.

2. Materials and methods

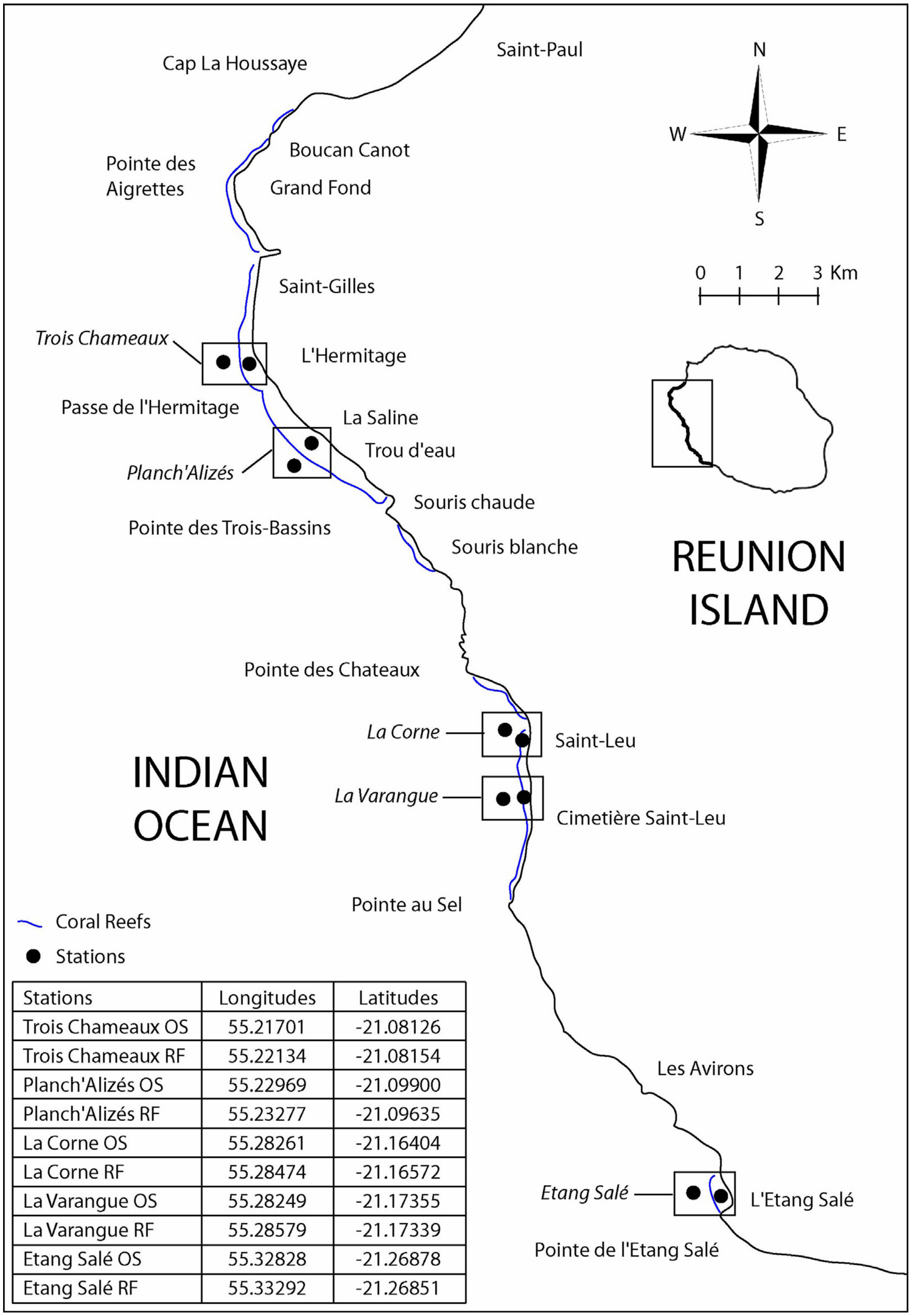
2.1. Study site

Réunion Island is a mountainous volcanic island in the Mascarene Archipelago in the southwest Indian Ocean. It is located 690 km east of Madagascar (21.06° N, 55.33° E) (Fig. 1). Reefs occur only on the west and southwest coasts of the island (Pinault et al., 2014a,b; Tessier et al., 2008). These fringing reefs are typical of Indian Ocean reefs and form a narrow band almost 25 km long along 12% of the island's coast (Pinault et al., 2013b). Although relatively sheltered from trade winds, they are exposed to high-energy wave conditions (Naim, 1993) and can be divided into three geomorphological zones: (i) an outer slope exposed to currents and swell, (ii) a reef front exposed to high-energy waves and (iii) a protected back reef and reef flat in shallow water (Battistini et al., 1975; Montaggionni and Faure, 1980). Réunion Island reefs are considered to be heavily degraded (Tessier et al., 2008) compared to other Indian Ocean reefs.

The western side of the island is the driest, with an average of 570 mm of annual rainfall, occurring mainly in the hot season (October to March) and especially during cyclones (Naim, 1993). In February 2007, Cyclone Gamède dumped a record amount of precipitation as it passed over Réunion Island (Quetelard et al., 2009). The cyclone had a particularly significant impact on the outer reef slopes of the west coast (Tourrand et al., 2013).

2.2. Sampling methods

The Marine Nature Reserve of Réunion Island was created in February 2007 to protect the island's coral reefs. It hosts 30 monitoring stations along the west coast, which are surveyed annually by the Reef Check program or by research scientists. In this study, we used 5 sites (Fig. 1) with two stations each, on the outer slope (OS) and reef flat (RF). The reef flat stations had depths between 0.5 m and 1 m and were located less than 300 m from the shore. The outer slope stations had depths ranging from 8 m to 12 m and were located between 400 m and 700 m off the coast. Since 2003, these 10 stations have been surveyed annually by a scientific team from October to May that extends through the hot season to the beginning of the austral winter.



Stations	Longitudes	Latitudes
Trois Chameaux OS	55.21701	-21.08126
Trois Chameaux RF	55.22134	-21.08154
Planch'Alizés OS	55.22969	-21.09900
Planch'Alizés RF	55.23277	-21.09635
La Corne OS	55.28261	-21.16404
La Corne RF	55.28474	-21.16572
La Varangue OS	55.28249	-21.17355
La Varangue RF	55.28579	-21.17339
Etang Salé OS	55.32828	-21.26878
Etang Salé RF	55.33292	-21.26851

Fig. 1. Location of the five sampling sites along Réunion Island west coast. Each site was divided into an outer slope (OS) station and a reef flat (RF) station for sampling purposes.

2.2.1. *Line Intercept Transect (LIT) method*

The entire dataset for this study was collected using the LIT method, which consists of recording the lengths of each successive type of benthic substrate underlying a tape (Loya, 1972) (Fig. 2). Where the tape did not touch the substrate, the substrate type lying directly underneath the tape was recorded. At each station, three 20 m transects were sampled for a total length of 60 m. Transects were laid perpendicular to the coast with a distance of 5 m between each transect. The percent cover of a category on a transect consisted of the total length of the category divided by the total length of the transect (2000 cm).

$$\text{Percent cover} = 100 \times \text{Total length of category/Total length of transect.}$$

The percent cover at a given station consists of the mean of its three transects.

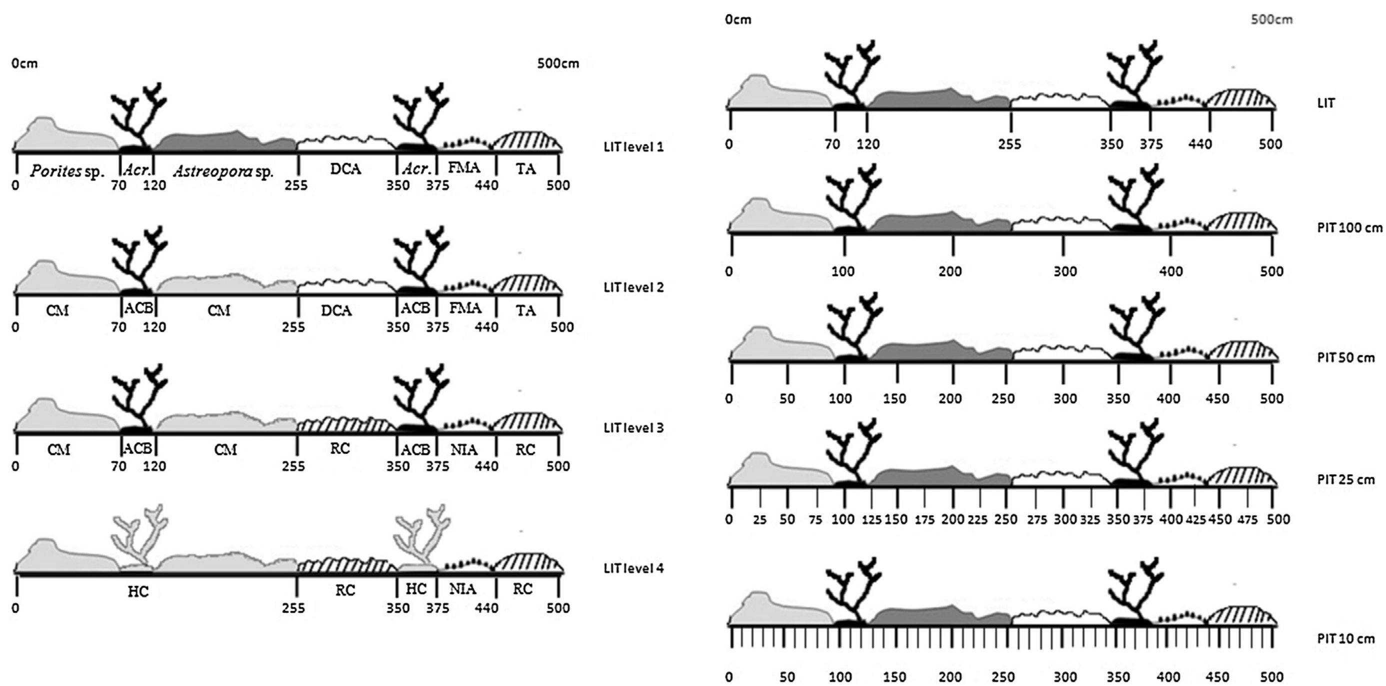


Fig. 2. Illustration of sampling methods on a 5 meters transect: four levels of identification using LIT (left) and four different PIT intervals (right).

2.2.2. Point Intercept Transect method

The PIT method is a linear method similar to LIT, with the exception that the benthic substrate is recorded only at fixed intervals along the transect without recording any length measurement (Dodge et al., 1982; Hill and Wilkinson, 2004). In this study, we compared the most frequently used intervals: 10 cm (Harris and Sheppard, 2008; Francini-Filho et al., 2013), 25 cm (Adjeroud et al., 2009) and 50 cm (Augustin et al., 1997; Hodgson, 1999) (Fig. 2). We also added a 100 cm interval to explore the lower limit of necessary sampling effort. This yielded respectively 200, 80, 40, and 20 sampling points for each transect. These intervals will be cited respectively as PIT 10, PIT 25, PIT 50 and PIT 100 in the study.

In order to study the influence of the sampling methods only, without variability between observers or “placement error”, the PIT method was not implemented in the field, but extracted from the dataset collected using the LIT method. Only the values measured at the fixed intervals of 10, 25, 50 and 100 cm were used. The percent cover of a category on a transect consisted of the number of sampling points where it was recorded divided by the total number of sampling points on the transect (respectively 200, 80, 40, and 20 points sampled for the intervals considered).

$$\text{Percent cover} = 100 \times \text{Number of points where the category is recorded}/\text{Total number of points on the transect}$$

The percent cover at a given station consists of the mean of its three transects.

2.2.3. Four levels of identification of benthic categories

Four levels of identification of benthic categories were compared, from the most detailed to the most simplified.

Level 1 consisted of recording the 30 descriptive categories described by English et al. (1997) with hard corals identified to genus level (Table 1).

Level 2 consisted of recording the 30 categories described by English et al. (1997) with corals recorded by growth form, which provides ecological information such as the response of corals to stress (Edinger and Risk, 2000; Naim, 2006; Hennige et al., 2010) and the role played by corals for other organisms such as fish (Chabanet et al., 1997; Bollard et al., 2013). For one genus, growth forms may vary according to the age of the colony and the environmental conditions. In this study, the correct assignment of growth form from level 1 to level 2 was possible because the original data recorded both genus identity and growth form. This was possible because the original data recorded both genus identity and growth form (for genera with multiple growth forms), enabling use of the data at both Levels 1 and 2. The only taxonomic information recorded for the coral growth forms was the distinction between *Acropora*/non-*Acropora*. This is standard practice in many programs (see English et al., 1997), as *Acropora* is the coral genus most widely used as a bio-indicator in the Indian Ocean. Levels of identification 1 and 2, which are recommended for scientific surveys (English et al., 1997; Hill and Wilkinson, 2004), are categorized as ‘expert’.

Levels 3 and 4 were made by merging categories with common ecological characteristics in order to obtain new broader categories that were increasingly fewer in number.

Level 3 was an intermediate identification level based on the Reef Check program (Hodgson, 1999), with the addition of growth forms of hard corals including *Acropora*/non-*Acropora* distinctions, consisting of 19 benthic substrate categories (Table 1). In contrast to level 2, encrusting *Acropora* and branching non-*Acropora*, which are rarely observed in the southwestern Indian Ocean and are difficult for non-specialists to identify, were not included.

Level 4 was the lowest level of identification, comprising 10 categories of the Reef Check monitoring protocol (Hodgson, 1999). Scleractinian corals were grouped as ‘hard coral’ and most algae as ‘macroalgae’. In the abiotic categories, bare substrate, which forms a solid substrate to which corals can attach, was distinguished from sand and rubble, which do not permit coral settlement.

2.3. Data analysis

Percent cover data were normalized using arcsine square-root transformation prior to statistical analysis (Legendre and Legendre,

Table 1
Benthic categories and codes used across the four levels of identification. Different codes were adopted by different authors for their protocols, but the hierarchy across identification levels is explicit as presented here. AA: Algal assemblage; ACB: *Acropora* branching; ACD: *A.* digitate; ACE: *A.* encrusting; ACS: *A.* submassive; ACT: *A.* tabular; CA: Coralline algae; CB: Non-*Acropora* Coral (nac) branching; CE: nac encrusting; CF: nac foliose; CHL: nac *Heliopora*; CM: nac massive; CME: nac *Millepora*; CMR: nac mushroom; CS: nac submassive; CTU: nac *Tubipora*; DC, RKC: Dead coral, Recently killed coral; DCA: Dead coral with algae; FMA: Fleshy macroalgae; HA *Halimeda*; HC: Hard coral; NIA: Nutrient indicator algae; OT: Others; R, RB: Rubble; RC, RCK: Rock; S, SD: Sand; SC: Soft coral; SI: Silt; SP: Sponges; TA: Turf algae; WA: Water; ZO: Zoanthids.

Categories	Level 1	Level 2	Level 3	Level 4
Hard coral:	*Acropora*	ACE	ACE	HC
Acropora		ACS	ACS	
		ACD		
		ACB	ACB	
		ACT	ACT	
Non-*Acropora*	*Acanthastrea*	CE	CE	
	Echinophyllia			
	Echinopora			
	Favia			
	Favites			
	Galaxea			
	Goniopora			
	Montastrea			
	Leptoseris	CF	CF	
	Pavona			
	Turbinaria			
	Caulastrea	CS	CS	
	Montipora			
	Pocillopora			
	Psammocora			
	Fungia	CMR		
	Stylophora	CB		
	Alveopora	CM	CM	
	Astreopora			
	Goniastrea			
	Hydnophora			
	Leptoria			
	Platygyra			
	Porites			
	Millepora	CME	CME	
	Tubipora	CTU	OT	
	Heliopora	CHL		
Other fauna:	ZO	ZO		OT
	OT	OT		
	SC	SC	SC	SC
	SP	SP	SP	SP
Algae:	AA	AA	NIA	NIA
	HA	HA		
	FMA	FMA		
	TA	TA	RC	RC
	CA	CA		
	DCA	DCA		
Abiotic:	RCK	RCK		
	DC	DC	RKC	RKC
	R	R	RB	RB
	SI	SI	SI	SI
	S	S	SD	SD
	WA	WA		

1998). The Bray–Curtis asymmetrical coefficient was used to create dissimilarity matrices because it is less sensitive to the presence of double zeros than other coefficients (Bray and Curtis, 1957; Legendre and Legendre, 1998; Anderson et al., 2011). The statistical analyses were performed with the Plymouth Routines In Multivariate Ecological Research Version 6 (PRIMER v6, Clarke and Gorley, 2006) and the 'Vegan' package (Oksanen et al., 2008) of R software (R Development Core Team; www.r-project.org).

In order to compare the performance of the LIT method at each level of identification, we studied the spatial and temporal variability of the benthic substrate cover according to two geomorphological zones (outer slope vs. reef flat) and two sampling periods (before vs. after Cyclone Gamède). Cyclone Gamède can be considered as the main disturbance that occurred in the area between 2003 and 2013. The data from 2003 to 2013 were analyzed using non-metric multidimensional scaling (MDS) for each resolution level. In each MDS scatterplot, stations with very similar benthic communities were grouped by level of similarity indicated by cluster overlays. A Permutational Multivariate Analysis of Variance (PERMANOVA, Anderson, 2001) was then performed to assess whether the stations had significantly different benthic communities according to the geomorphology (outer slope vs. reef flat) or period (before vs. after the cyclone). In order to remove the predominant effect of the sampling site in the analysis of the spatial and temporal variability of the data, we added 'Site' as a factor in PERMANOVA (three-way crossed PERMANOVA with the terms Site, Geomorphology and Period added sequentially). When significant variability was found, a Similarity Percentage (SIMPER) routine (Clarke, 1993) showed the main benthic categories contributing to dissimilarity between the two different periods or geomorphological units.

PIT and LIT methods were then compared at each level of identification in terms of (i) percent cover of the benthic substrate categories, (ii) the number of categories recorded, and (iii) the global benthic community assemblage. For each substrate category, if the difference between percent covers estimated by both methods was less than 5%, we supposed that the PIT method provided a correct cover for this category. The benthic community assemblage was shown by Pearson correlation coefficients (Legendre and Legendre, 1998) between the similarity matrix using data sampled with the LIT method and similarity matrices using data from the PIT method at intervals of 10, 25, 50 and 100 cm. The sampling effort was also estimated for each method, based on the time spent in the field to survey one station (three transects) according to studies by Dodge et al. (1982) and Segal and Castro (2001) as well as information provided by the Marine Nature Reserve. Costs arising from increased sampling time (e.g. boat rental, diving equipment, number of days worked by the observers, etc.) were not taken into account because of their great variability and the equipment and implementation costs are identical for the PIT and LIT methods (Hill and Wilkinson, 2004). At each level of identification, we sought to determine the PIT interval with the optimal balance between sampling effort (number of points measured) and information obtained (compared to that provided using the LIT method). Relationships of correlation coefficients between the PIT and LIT matrices to the intervals of the PIT method were plotted. The interval showing a decrease in the rate of increase in correlation (the inflection point on the curve) was considered the optimum. This analysis was based on the species–area curve method (Gleason, 1922; Bortone et al., 1989).

3. Results

3.1. Spatial and temporal variability in benthic communities at each level of identification using the LIT method

MDS scatterplot of level of identification 1 (Fig. 3a) revealed a clear distinction between the two geomorphological units with the reef flat stations to the left and the outer slope stations to the right. This suggests pronounced differences in their community structure. The vertical axis distinguished the stations within each geomorphological unit. The Planch'Alizes RF and La Corne OS stations were isolated from the other reef flat and outer slope stations. The MDS did not reveal an impact of the cyclone in the reef flat stations. However, in the outer slope stations, samples collected after the cyclone generally appeared to the bottom right relative to the samples collected before the cyclone. The PERMANOVA analysis (Table 2) confirmed that the benthic communities were

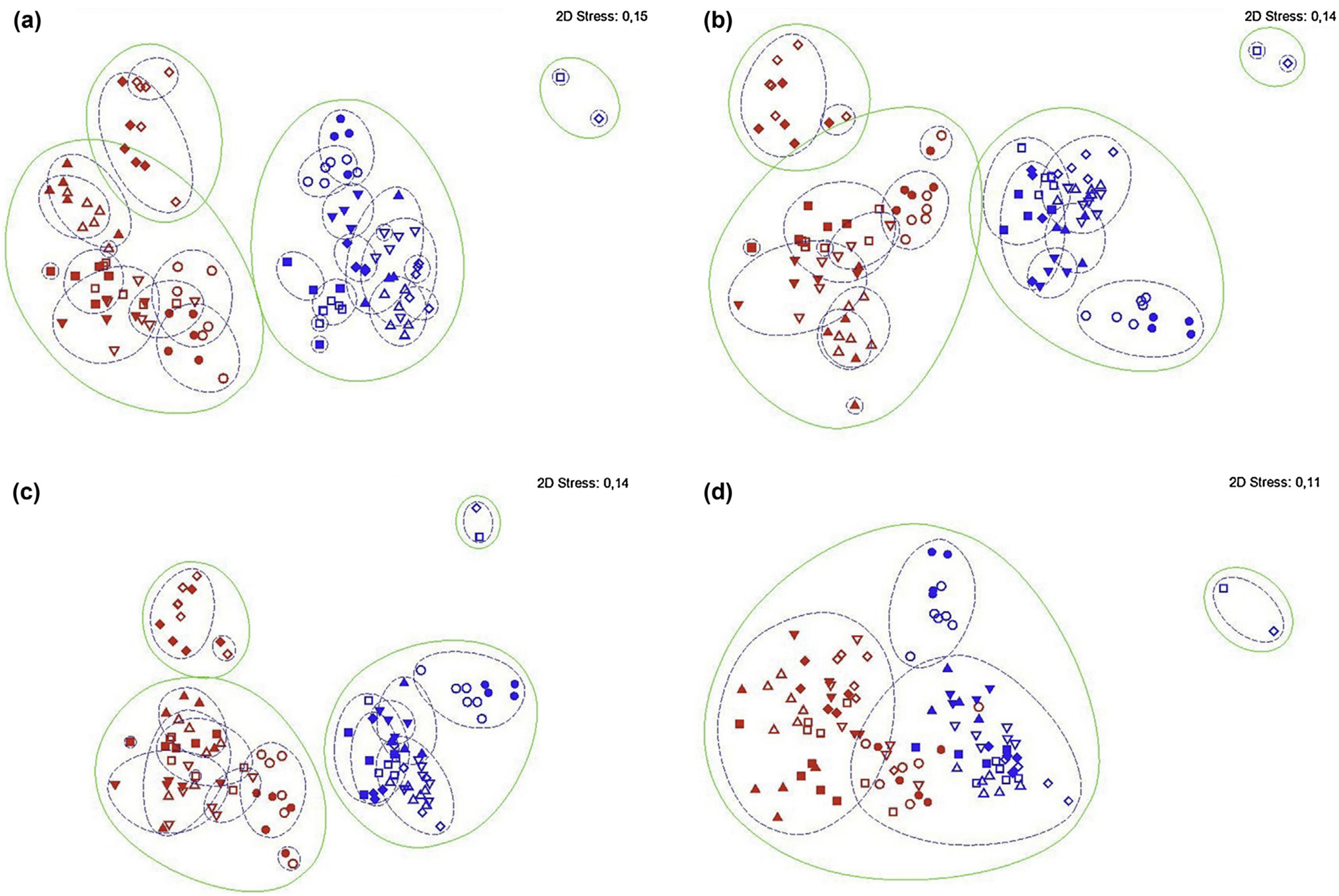


Fig. 3. Non-metric MDS ordination of percent cover data collected at the five sites surveyed between 2003 and 2013 for levels of identification 1 (a), 2 (b), 3 (c) and 4 (d). The overlay clusters show similarity between the stations (shown by the symbols). Red: reef flat, blue: outer slope, filled symbol: before the cyclone; open symbol: after the cyclone, ■: Trois Chameaux, ⧫: Planch'Alizés, ●: La Corne, ▼: La Varangue, ▲: Etang Salé. Green circles: more than 60% of similarity, dotted circles: more than 80% of similarity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Results of the three-way crossed PERMANOVA, testing differences between sites, geomorphologies (outer slope vs. reef flat) and periods (before vs. after Cyclone Gamède). The significance is presented as: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

	Level 1	Level 2	Level 3	Level 4
Site	0.001***	0.001***	0.001***	0.001***
Geomorphology	0.001***	0.001***	0.001***	0.001***
Period	0.018*	0.01**	0.01**	0.074

significantly different between sites ($p = 0.001$), geomorphological units ($p = 0.001$) and the periods before and after the cyclone ($p = 0.018$). The SIMPER routine showed that outer slope stations were characterized by a high cover of algal turf, soft corals and of the corals *Porites*, *Astreopora* and *Pocillopora*. Reef flat stations were characterized by the presence of sand and a higher cover of *Acropora*. La Corne OS station was set apart by the dominance of *Acropora* and a low algal turf cover, despite its location on the outer slope. The Planch'Alizes RF station was set apart by the dominance of the coral genera *Montipora* and *Porites*. The dissimilarity between periods before and after the cyclone was mainly shown in a dramatic decrease in the cover of *Acropora*. Other genera showing a decrease in cover were *Galaxea* and *Echinopora*. Coralline algae also decreased after the cyclone. By contrast, the relative cover of *Astreopora*, *Pocillopora* and *Porites* increased, as did algal turf and sand. Overall a change in the composition of the benthic community occurred.

MDS scatterplot of level of identification 2 (Fig. 3b) also revealed a separation between geomorphological units and sites. The impact of the cyclone was also revealed in the outer slope stations, with samples collected after Cyclone Gamède generally appearing to the top right relative to the samples collected before the cyclone, except for La Corne OS station. The PERMANOVA analysis revealed a significant difference between sites ($p = 0.001$), geomorphological units ($p = 0.001$) and periods ($p = 0.01$). The SIMPER routine showed that outer slope stations were characterized by massive, submassive and encrusting non-*Acropora* corals, while reef flat stations were characterized by branching *Acropora* and higher cover of submassive non-*Acropora*. The non-coral categories accounting for most of the dissimilarity between geomorphological units had the same percent contribution as in level 1. La Corne OS and Planch'Alizes RF stations again show an exception to the general trend. The former was set apart by the dominance of submassive *Acropora*, and the latter by the very low cover of the genus *Acropora* and the dominance of submassive non-*Acropora*. On outer slope stations, the impact of Cyclone Gamède was shown by the dramatic decrease of submassive and branching *Acropora* cover, while massive corals became predominant.

The MDS scatterplot of level 3 (Fig. 3c) also distinguished geomorphological units, sites and periods. The PERMANOVA analysis revealed significantly different benthic community structures between sites ($p = 0.001$), geomorphological units ($p = 0.001$) and periods ($p = 0.01$). The coral growth forms and non-coral categories accounting for most of the dissimilarity between geomorphological units and periods were the same as those in level 2. Categories

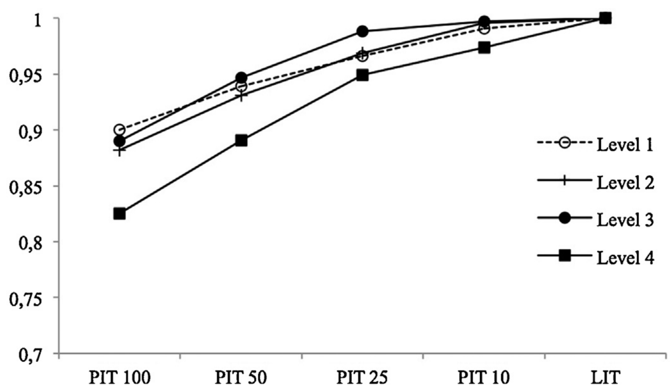


Fig. 4. Pearson correlation coefficients between the similarity matrices obtained from the PIT and LIT methods according to the PIT intervals, for each level of identification.

that were merged for level 3, such as bare rock, zoanthids or hard macroalgae, corresponded to very low percent covers in our dataset and only marginally contributed to the variability within geomorphological units and periods.

The MDS scatterplot of Level 4 (Fig. 3d) differentiated the geomorphological units less clearly than the other levels. La Corne OS station appears far from the other outer slope stations. Nevertheless, the PERMANOVA analysis revealed significant differences in the benthic communities between sites ($p = 0.001$) and geomorphological units ($p = 0.001$). However, there was no significant difference between periods ($p = 0.074$). The SIMPER routine showed that the outer slope stations were characterized by soft corals and algal turf, while the reef flat stations were characterized by a higher percent coral cover.

Planch'Alizes OS and Trois Chameaux OS stations sampled in 2010 showed unusual benthic communities, revealed by their isolated position on the MDS scatterplots at all the levels of identification. These samples were characterized by a temporary proliferation of macroalgae in 2010, which was not recorded in the other years.

3.2. Comparison of the PIT and LIT methods

The comparison of the two methods revealed, at all levels of identification, positive and significant correlation coefficients between the matrix generated from the LIT method and the matrices generated from the PIT methods for each interval (Fig. 4).

Identification level 1 showed the highest loss of benthic categories due to conversion from LIT to PIT (Fig. 5a). Conversely, it showed the lowest error in percent cover estimation (Fig. 5b). The correlation-curve for identification level 1 showed an inflection for the 10 cm interval (Fig. 4), which is therefore the optimum between sampling effort and information obtained for this level of identification. For this method, the correlation coefficient between matrices was high (0.99) and percent covers of the categories were identical to those obtained with the LIT method (±5%). Less than 3% of the records along the line were omitted (3 records out of 110), representing less than 0.1% of the total percent cover. The PIT 10 method is thus a reliable proxy for the LIT method when it is implemented with identification level 1. Using longer intervals increased the number of omitted records (15% at 25 cm interval, 27% at 50 cm, and 42% at 100 cm), however, the correlation coefficient remained higher than 0.90 and error in cover estimation less than 5%.

Level 2 resulted in a smaller decrease in the number of benthic categories recorded when converting LIT to PIT (Fig. 5a). The correlation-interval curve (Fig. 4) also showed an inflection for the 10 cm interval. This interval thus seems to be the optimal compromise between sampling effort and information obtained for this level of identification, and is a reliable proxy for the LIT method when it is implemented with the identification level 2 (with a correlation coefficient of 0.99). For PIT 10 there were no benthic categories omitted and the percent covers were very similar to those obtained with the LIT method (Fig. 5). The 25 cm interval also proved to be a good proxy, with less than 5% of omitted categories and similar percent covers. The proportion of non-observed categories increased with the length of the PIT interval, although the correlation coefficient remained high, at >0.90.

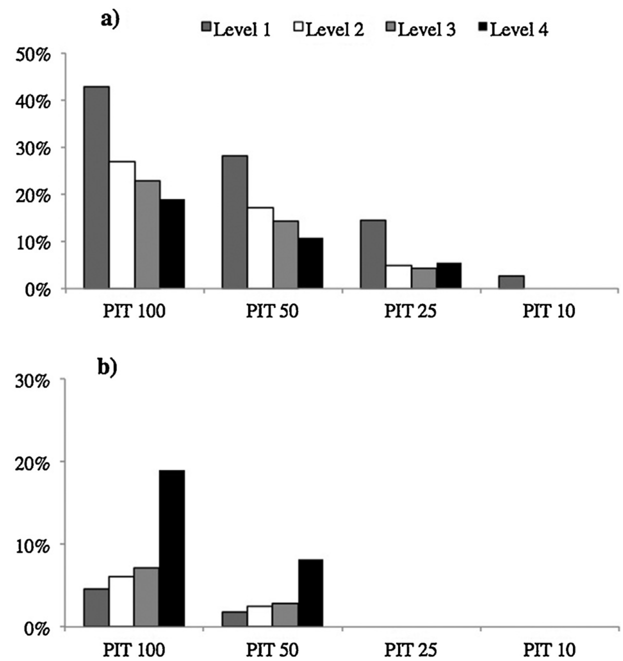


Fig. 5. Errors of each PIT interval and level of identification compare to LIT: (a) percentage of omitted records, and (b) additive percentage error in cover estimate.

Level 3 resulted in a better preservation of the number of benthic categories when converting the LIT into the PIT method than levels 1 and 2 (Fig. 5). The optimum balance between sampling effort and information obtained occurred for the 25 cm interval (Fig. 4). For PIT 25 the proportion of omitted categories was less than 5%, with a high correlation coefficient (0.98). For larger intervals, the proportion of omitted categories became moderate to high (15% at 50 cm and 23% at 100 cm), and the error in cover estimation was slightly higher than for level 2 (3% at 50 cm and 7% at 100 cm).

Finally, level 4 minimized the number of omitted benthic categories when converting the LIT into the PIT method, but had the highest error in percent cover estimation (Fig. 5). As in level 3, the 25 cm interval showed the optimum between sampling effort and information obtained, with a correlation coefficient of 0.94 (Fig. 4). At this interval, only 5% of the categories were omitted and the percent covers were similar to those obtained with the LIT method. For larger intervals, the number of omitted benthic categories increased slightly, but the error in cover estimation was almost three times as high as that of level 3 (8% at 50 cm and 19% at 100 cm).

Thus, the higher the level of identification, the higher the proportion of omitted benthic categories (Fig. 5a), but the lower the error of percent cover estimation (Fig. 5b).

4. Discussion

4.1. Comparison of the different levels of identification using the LIT method

In our comparative analysis, all four levels of identification using the LIT method showed that the distinction between geomorphological units, characterized by different hydrodynamic conditions and benthic communities (Connell et al., 1997; Guillemot et al., 2010), was significant. The characteristics of reef flat stations as having (i) the presence of sand and (ii) the dominance of *Acropora* with branching, tabulate or digitate growth forms is similar to the results published by Naim (1993, 2006). Naim (1993) also explained the unusual benthic community assemblage of the Planch'Alizes RF station as the result of substantial eutrophication, leading to the dominance of coral genera and growth forms adapted to these conditions, for example submassive *Porites* and *Montipora* (Meesters et al., 1996; Naim, 2006; Tourrand et al., 2013). The characteristics of the outer slope stations as having algal turf, soft corals and the dominance of coral genera *Astreopora* and *Pocillopora* with massive, submassive or encrusting coral growth forms is also in line with the results of Chabanet et al. (1997). The unusual composition of La Corne OS station can be explained by its location close to the reef edge, resulting in significant water movement and very high resilience of the coral population to physical disturbances (Montaggionni and Faure, 1980).

Several studies have found that outer slope stations were most strongly affected by Cyclone Gamède (Connell et al., 1997; Adjeroud et al., 2009; Scopélitis et al., 2009; Pinault et al., 2014a,b). Changes in the composition of the benthic community revealed in this study support these results. Branching, digitate and submassive *Acropora*, which are more fragile and have less attachment surface, were more affected than massive corals, which became predominant (Done, 1992; Harmelin-Vivien, 1994). Leveled areas, stripped of all attached benthic organisms, are then colonized by opportunistic and fast-growing organisms such as algal turf (Meesters et al., 1996; Guillemot et al., 2010).

The abundance of macroalgae observed in 2010 (proliferation of *Dictyota* sp.) at the Planch'Alizes OS and Trois Chameaux OS stations could be explained by an unusual increase in water temperature that year, which has previously been observed at reef flat stations (Naim, 1993), or by temporary pollution, possibly from phosphates (Cuet et al., 1988).

Despite overall consistency in patterns revealed by the four levels of identification, our comparative study showed that all levels do not reveal all the spatial and temporal characteristics studied. Each level enables the analysis of indicators, which are useful to a greater or lesser degree in different studies. Level 1 enabled the comparison of the relative abundance of different coral genera and the description of genus richness and diversity. These indicators are often used in scientific studies (Connell et al., 2004; Francini-Filho et al., 2013). Studying certain selected genera that are bio-indicators is also often useful in identifying the impact of disturbances (Meesters et al., 1996; Adjeroud et al., 2009; Hennige et al., 2010). Moreover, although coral genera with the same growth forms generally react in the same way to cyclonic disturbances (Done, 1992; Edinger and Risk, 2000), there are sometimes exceptions. Thus, while most massive corals such as *Astreopora* and *Porites* (which had a massive morphology on outer slope stations) showed a relative increase in the coral community after Cyclone Gamède, the percent cover of the massive coral *Platygyra* decreased. This coral genus is usually described as resistant to cyclones (Foster et al., 2008, 2011). Identification Level 1 thus allows a detailed description and understanding of ecosystem functionalities.

Level 2 equally provides the main information describing a reef station. The coral growth forms and the distinction between *Acropora*/non-*Acropora* genera are in fact reliable indicators as they respond differently to disturbances (e.g. cyclones, eutrophication) and these categories have been used in numerous scientific studies (Edinger and Risk, 2000; Naim, 2006; Guillemot et al., 2010; Hennige et al., 2010). However, our analysis showed that some detailed non-coral categories (*Tubipora*, zoanthids, bare rock, etc.), recorded in levels 1 and 2 but absent in level 3, were found in very small proportions and only marginally contributed to the spatial and temporal variations of the data. Moreover, in many studies using level 2 during data collection, the 'abiotic' or 'other invertebrates' categories are often grouped together for analysis (e.g. Kumara et al., 2008; Rajasuriya, 2008).

In level 3, the merger of level 2's non-coral categories into a reduced number of broader categories led to a limited loss of information. The reduction of benthic categories is an opportunity for methodological simplification, making the English et al. (1997) LIT method more accessible to users with intermediate expertise, while retaining the principal and most frequently studied ecological information.

Level 4 led to a significant loss of information since the coral growth forms were not recorded. This level allows the collection of the basic indicators used in all studies, such as the percent cover of abiotic substrate, hard coral or macroalgae (Obura et al., 2008; Guillemot et al., 2010). However, most scientific researchers, marine nature reserve staff, environmental consultants analyze more precise indicators, thus this level of identification is suitable only for programs aiming to identify general trends.

To summarize, a survey protocol using the more precise biological indicators (level 1) requires a high level of expertise and is restricted to a limited number of scientists (Hill and Wilkinson, 2004). This level of identification is advisable only if the objectives of the survey require the analysis of taxonomic indicators (e.g. scientific programs studying alpha, beta or gamma diversity, Shmida and Wilson, 1985). Using less detailed levels of identification inevitably leads to the loss of these taxonomy-based indicators. Survey protocol using level 2 involves more constraints than one based on level 3, while the most common indicators used in studies in the Indo-Pacific are common to both levels (Kumara et al., 2008; Rajasuriya, 2008; Guillemot et al., 2010). A survey protocol using level 4 is the easiest to implement (Hodgson, 1999), but leads to a loss of information. Thus, given its technical accessibility, level 3 seems to be the best compromise between the expertise and effort required and the information obtained. In fact, community-based surveys using the Reef Check protocol with scientific goals have increased the level of identification either to distinguish *Acropora* and non-*Acropora* (Harding et al., 2003) or to identify coral genera (Augustin et al., 1997).

This is in line with Done (1977) results. Although he compared 4 units of coral cover (quantitative absolute, quantitative relative, graded and binary) instead of levels of identification, he showed that the 4 units provided little difference between classifications of coral sites. As in our study, the least detailed level failed to indicate all the site zonations. The graded level, which could be compared to our level 3, indicated a very similar zonation and its use should allow the users to survey more sites per unit of time.

4.2. Comparison of the LIT and PIT methods

The mean sampling times required for the LIT and PIT methods, at different intervals and levels of identification, are shown in Table 3. The sampling time for the PIT method depends mainly

Table 3
The mean census time in minutes, by method and level of identification, for 20 m transect. Times include transect installation time.

Method and interval	Level			
	1	2	3	4
LIT	35	30	25	20
PIT 10 (200 sampling points)	25	25	25	25
PIT 25 (80 sampling points)	15	15	15	15
PIT 50 (40 sampling points)	10	10	10	10
PIT 100 (20 sampling points)	7	7	7	7

Table 4
Recommended levels of identification and stakeholders' needs.

Stakeholder	Level 1	Level 2	Level 3	Level 4
Community-based surveys	– – Too much expertise required	– – Too much expertise required	++ Adapted	+ Reliable for broad-scale trends
Assessment agencies	– Specialization required	– Specialization required; often unused additional data	++ Adapted	– – Precision too low for the objectives set
Marine nature reserve staff	++ Adapted	– Often unused additional data	++ Adapted	– – Precision too low for the objectives set
Scientific researchers	++ Adapted	– Absence of taxonomy-based indicators	– Absence of taxonomy-based indicators	– – Precision too low for the objectives set

on the interval used between sampling points. However, the taxonomic level of identification has very little impact on the time spent in the field. The time necessary to note a category code is the same for any category, whether it be genus, coral growth form, hard coral, etc., providing that the observer has enough expertise to make identifications at the required taxonomic level. Even with a short interval of 10 cm and a high identification level, the PIT method is much less time-consuming than the LIT method. Increasing the PIT interval and decreasing the identification level leads to maximum saved effort. For the same time spent in the field, more transects can be surveyed using the PIT method than the LIT method, thus the PIT method allows scientists to study a larger area of the reef (Segal and Castro, 2001; Beenaerts and Vanden Berghe, 2005; Leujak and Ormond, 2007).

Yet users should be aware of the limits of PIT. Characteristic features of the studied reef should be taken into account in the sampling effort or this can lead to errors. For example, in this study, the PIT method did not record categories with less than 0.1% cover, especially at the 100, 50 and 25 cm intervals. This is in line with Segal and Castro (2001) and Lam et al. (2006), who also found that the use of the PIT method with sampling effort that was too low did not record rare categories. Leujak and Ormond (2007) also concluded that the lower the sampling effort, the less generic diversity was recorded. Moreover, using fixed intervals to survey the benthic substrate could result in under- or overestimation of studied categories (Zar, 1974) when the latter are regularly spaced along the reef, as has been shown for some corals (Endean et al., 1997). This error is reduced by decreasing the interval between sampling points.

Per 20 m transect and for each identification level, using the optimal PIT method determined in Section 3.2 rather than LIT saved 10 min for level 1, 5 min for level 2, 10 min for level 3, and 5 min for level 4. Thus we found that the protocols that saved most time in the field were PIT 10 at level of identification 1 and PIT 25 at level of identification 3; we recommend these protocols, providing that the limitations of the PIT method are not incompatible with the goals of a study.

4.3. Recommendation of the appropriate method and level of identification according to the goals of the survey

Four main kinds of coral reef monitoring stakeholders could be identified according to their increasing need for precision: (i) community-based networks, (ii) environmental impact assessment agencies and applicants, (iii) marine reserve managers, and (iv) specialist researchers. Although their objectives are often complementary, each of these stakeholders has specific goals that require the most appropriate survey method (Table 4).

Community-based surveys such as Reef Check (Hodgson, 1999) currently use the PIT 50 with a low level of identification (level 4). However, it is advisable to slightly increase the resolution to level 3 to distinguish coral growth forms, and 25 cm sample intervals would result in a better compromise between sampling effort and information obtained. This level would remain accessible to correctly trained volunteers (Harding et al., 2000). An additional certification could be integrated into the Reef Check program for experienced volunteers who are willing to improve their level of expertise. The level of identification and the sampling method should be adapted for each region according to the characteristic and the distribution of the coral communities.

Assessment agencies or developers performing ecological surveys have severe cost and time constraints and are rarely specialists in the identification of benthic communities. The method employed must, however, indicate potential changes in the benthic community following the implementation of a project (e.g. urban development, environmental compensatory mitigation measures, sanitation) while surveying impacted and control stations (Before After Control Impact, BACI protocols, Osenberg et al., 1994). Level 3 associated with PIT 25 would then optimize the time spent in the field, allow an increase in the number of replicates and therefore improve the statistical power of analysis. The use of key species and the assessment of function could also help to assess trade-offs between taxa and evaluate compensation due to impacts of a project, under the concept of "no net loss" mitigation (Dunford et al., 2004; Levrel et al., 2012).

Marine reserve management staffs generally select indicators that show the improvement or degradation of the health of the coral reef in order to assess the effectiveness of management actions (Halpern and Warner, 2002; Lison de Loma et al., 2008). Level 1 would certainly allow this goal to be reached with the most accuracy and precision. However, few managers have the required expertise to reliably conduct surveys at such a level (Hill and Wilkinson, 2004) and this would limit the area of reef surveyed. So the systematic use of this level of identification does not seem appropriate, especially in countries with large reef areas (Wilkinson, 2008). Level 3 used with PIT 25 is thus a good compromise. For a major disturbance (e.g. accidental pollution, a cyclone or coral bleaching), performing additional surveys at level 1 would, however, be advisable to precisely describe the impact on the coral community (Naim, 1993). If stakeholders want to assess the resilience of key species, and expertise and funding allow, some coral genera could be added to the level 3 categories for routine surveys.

The goal of specialist scientific researchers is usually to gain a detailed understanding of the workings of the coral reef ecosystem. To ensure the most exhaustive survey possible, level 1, used either with the LIT or PIT 10 methods (Edinger et al., 1998), seems the most suitable. These methods would provide data that allows statistical analyses in order to compare communities and to calculate dissimilarity distances between sites, which are frequently employed in scientific research (Augustin et al., 1997; Naim, 2006; Adjeroud et al., 2009; Burgess et al., 2010). The highest level of identification could also be enhanced to adapt the protocol to the survey goals; for instance, by adding certain well-known indicator species or detailing other categories such as soft corals or algae (Meesters et al., 1996; Hennige et al., 2010). However, it should be kept in mind that linear transect methods are not suitable for studying very fine-scale descriptors such as mortality or recruitment (English et al., 1997). For such objectives, area-based methods are more appropriate (Hill and Wilkinson, 2004).

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