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Previously unlisted scleractinian species recorded from the Great Reef of Toliara, southwest Madagascar

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Abstract
The scleractinian biodiversity of Madagascar is mainly known from one study performed in the Bay of Toliara (SW of Madagascar) in the 1970s. In the present study, this biodiversity was re-investigated 40 years later, at 2 sites previously considered as atypical, but now subject to high anthropogenic pressures. Results showed lower species diversity compared to the previous study, and to similar sites in the Indian Ocean region, but most of the well-represented genera were recorded. The occurrence of previously unrecorded species suggests that the scleractinian communities are changing, in addition to declining. The findings of the present study constitute a baseline of scleractinian structure studies, focused on diversity change. Further investigations on this reef must consider these changes, and management measures must be adapted to ensure greater efficiency.

Keywords: newly recorded species, scleractinians, biodiversity, Great Reef of Toliara, southwest Madagascar

Introduction
Coral reefs of Madagascar occupy an area of 2,400 km² along 1,400 km of the coastline (Cook *et al.*, 2000). They are particularly well distributed along the southwest coast. The reef system is dominated by the Great Reef of Toliara (GRT), while most of the coral reef types (barrier reef, fringing reef, patch reef, coral bank) are recorded (Clausade *et al.*, 1972). The GRT is among the most studied reefs of the Indian Ocean, especially in the 1960s and 70s (Pichon, 1978). It constitutes a refuge for diverse marine flora and fauna communities with more than 6,000 species recorded (ONE, 2002), including reef fishes (714 species; Harmelin-Vivien, 1979; Rasoarimalala, 2001), and benthic organisms such as sponges (125 species; Vacelet and Vasseur, 1971) and scleractinians (112 species; Pichon, 1978; Sheppard, 1998).

It is well known that the coral reefs of Madagascar, especially those in the southwest, are subject to intense social-ecological impacts that have caused unprecedented change. In the period of 50 years, the coral cover has decreased from >50% to around 5% (Harris *et al.*, 2010; Bruggemann *et al.*, 2012), reef fish species diversity has dropped to less than 30% (Ranaivomanana, 2006), while anthropogenic pressures, including destructive fishing, continues to increase due to the increasing number of fishing communities (Vasseur *et al.*, 1988; Toany, 1995; Salimo, 1997; Vasseur, 1997). In the years 2006 – 2011, more than 50 locally managed marine reserves were created as a solution to coral reef degradation and the decline of fishery products (Voajanahary, 2011; Todinanahary, 2013). Initially, these locally managed marine areas (LMMA) were socially well perceived and accepted by fishing communities, who were the main users and the principal managers, and Mahafina (2011) reported some success and benefits generated by LMMAs. However, most of them were not properly managed, and their status as protected areas was often not respected since

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2014, except for few of them (e.g. Marine Reserve of Rose Garden, Ankaranjelita, Soariake and Velondriake) where there is strong support from non-governmental organizations (NGOs) (Rocliffe and Peabody, 2012; Belle *et al*., 2009; Shane, 2012). The impacts of the establishment of these protected areas on the reef communities are poorly understood, especially for scleractinians of the GRT.

The study of Pichon (1978) is the only one that reported complete information about species richness and diversity of scleractinians in southwest Madagascar. Since then, new data about the reef building corals are very few (e.g. Sheppard, 1987; Sheppard, 1998; Harris *et al*., 2010; Bruggemann, 2012). Sheppard (1998) updated the scleractinian biodiversity patterns in the Indian Ocean (including Madagascar, based on Pichon (1978)). This author analysed the effect of taxonomic error in data (including redundant synonyms and species marked as "spp"), and reported that the number of coral species on the GRT was only 112 belonging to 57 genera, rather than 135 (Sheppard, 1987; 1998). Harris *et al*. (2010) reported a loss in scleractinian diversity based on sampling in 2008, and noted that the once great barrier reef of Toliara was in serious decline. The present study presents the results of a survey on scleractinians of GRT in 2015, on a few of stations surveyed by Pichon (1978). The survey aimed at determining the present scleractinian biodiversity in the Bay of Toliara by comparing 2 sites of different geomorphological structure on the GRT, and compares the results with some of those documented previously.

Materials and methods

Area of study

Two distinct sites were chosen for the sampling during the biodiversity survey (Fig. 1). The first site was the "Grande Vasque" (GV)). The GV is a basin of about 1 km in diameter situated on the flat of the barrier reef. GV is well protected from the swell, around 15 m deep, and its slopes are colonized by scleractinians, mainly in the first 8 m. GV is located in front of the main harbour of the region, near Toliara city. Two stations were defined and sampled on the GV; one on its southern part (GV South), the other on its northern part (GV North). The second site of the study was Nosy Tafara. Nosy Tafara (NT) is a complex of patch reefs located on the southern tip of the Great Barrier Reef of Toliara. NT is exposed to the swell and the waves generated by the dominant SW wind. Two stations were also defined and sampled in NT: the outer slope of Arakaivo, exposed to the open sea, and Velomitahy, a station protected by Arakaivo. Both sites were chosen because of the existence of old and more recent data (e.g. Voajanahary, 2011; Mahafina, 2011; Bruggemann *et al.*, 2012; Andréfouët, 2013; Sheridan *et al*., 2014a, 2014b; Todinanahary, 2013) and because they are among the most accessible sites in the Bay at any time of the year, and thus the most exposed to anthropogenic pressures.

Surveys and sampling

In the western Indian Ocean (WIO) region, the PRECOI ("Programme Régional Environnement de la Commission de l'Océan Indien") method is recommended for coral cover monitoring (Conand *et al*., 1997). This method, based on a combination of transects and quadrats, has been widely used for coral reef studies in Madagascar, but was limited to category levels for coral identification (see details in Conand *et al*., 1997). In the present study, the Point Intersept Transect (PIT) method was used (Hill and Wilkinson, 2004). Several coral reef research programmes have used the PIT method (e.g., Rogers *et al*., 1994), recommended by English *et al*. (1997), and adapted by others to fit with regional aspects and research focus (Beenaerts and Berghe, 2005). It was chosen and adapted for its efficiency for coral species diversity monitoring (Beenaerts and Berghe, 2005).

At each station, 15 transects of 10 m were undertaken on the reef slope, at 8 to 15 m depth, by 3 to 4 divers between January and August 2015. The transect line was a flexible measuring tape, marked in millimetres. The line was kept close to the benthic communities using small weights. To allow the recording of small coral colonies (< 10 cm including juveniles which were abundant on the sites), the line was marked every 5 cm, and the sessile benthic organism or substrate directly beneath the mark was recorded. During the survey the common set of cover categories for the WIO (see details of categories in Conand *et al*., 1997) were used. Live coral species were identified to genus level where possible, using the *in-situ* Coral finder identification guide (Kelley, 2011), followed by an in-lab skeletal morphology analysis based on the work of Veron (2000). All the observed colonies were photographed and two 2 cm to 5 cm branches were sampled for skeletal morphology analysis.

Calculation of ecological parameters

Coral species richness, species dominance and diversity were calculated for each station. Richness was

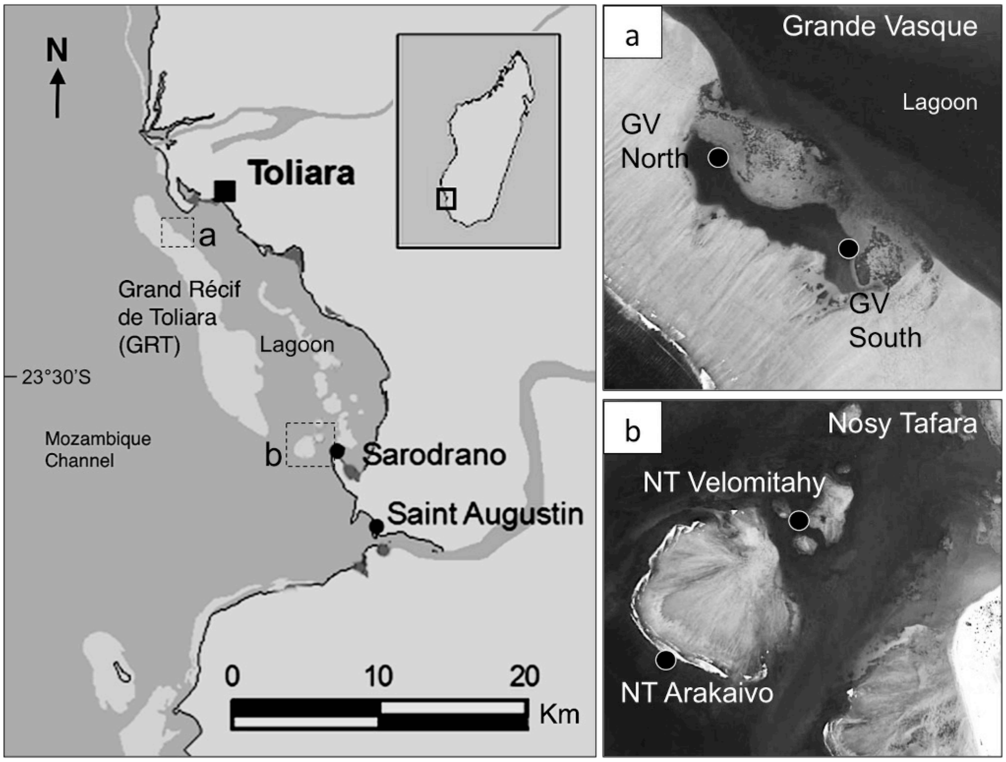

Figure 1. Locality of the sites and stations.

calculated as the total number of species under the transect line. Species dominance was calculated as the ratio of the abundance of each species and the total number of recorded colonies on the transect, reported as percentage. The Shannon diversity index (Shannon and Weaver, 1964) was calculated at the level of coral species.

To characterize the community at each station, the constancy and fidelity index of each species in the coral community (station) were also calculated. Constancy was calculated by dividing the number of records (transects) containing the species by the total number of records within the community. Fidelity was deduced by dividing the constancy of a species by the sum of the constancy of that species at all the stations as follows:

$$C_{A/1} = (R_A/R_1)*100$$
$$F_{A/i} = (C_{A/1} / \sum^{n}_{1} C_A)*100$$

where $C_{A/1}$: constancy of the species A at station 1
R_A: number of records of the species A
R_1: total number of records for the station 1
F_{Ai}: fidelity of the species 1 to the station i

The most characteristic species, and common or rare species, were identified for each station using the constancy and fidelity values on the basis of the following categories.

Constancy index:
75 % - 100 %: Constant species
50 % - 74.9 %: Common species
25 % - 49.9 %: Less common species
< 24.9 %: Rare species
Fidelity index:
75 % - 100 %: Selective species
50 % - 74.9 %: Preferential species
25 % - 49.9 %: Indifferent species
< 24.9 %: Occasional species

Statistical analysis

All statistical analyses were performed using the R software (R Core Team, 2015). Descriptive statistics were calculated first. Normality of the data was determined using a Shapiro-Wallis test, and homogeneity of the variance was calculated using Levene's test. For species richness analysis, data were transformation into log(x+1). Significance of difference in means were determined using one-way ANOVA, at a level of 5%. The Tukey multiple comparison test was used for pairwise comparison between stations. Principal component analysis (PCA) and hierarchical cluster dendrograms of species and stations were performed to characterize the distribution of the species and the similarity of the stations.

Results

Characterisation of the scleractinian communities

Richness and diversity of coral species

Species richness varied significantly from 4.2 ± 1.4 (mean ± SD) to 9.1 ± 2.2 (mean ± SD) at the studied stations ($p<0.001$). The lowest richness was observed at the GV site, while NT presented the highest values (significant difference between both sites, $p<0.001$). Arakaivo station had significantly higher species richness than the three other stations (Table 1 and 2), between which no significant difference was observed.

Similarly to richness patterns, Shannon diversity results show significantly higher diversity at NT as compared to GV ($p<0.001$). However, this difference was highly influenced by the station at Arakaivo, which had the highest and most significant diversity index, compared to than the three other stations, between which no significant difference was observed (Table 1 and 2). In addition, GV North and GV South showed no significant difference in richness and diversity (Table 2).

Recorded species: abundance, dominance and distribution

A non-exhaustive total of 36 species from 14 genera and 9 families were recorded at the 4 monitored stations (Table 3 and 4). Acroporidae was the most represented family with 14 species recorded, followed by Pocilloporidae with 9 species represented, and Poritidae with 4 species. Agaricidae, Oculidae and Fungidae were represented by 2 species each, and Favidae, Euphyllidae and Mussidae by 1 species each (Table 4). The overall dominance values placed *Porites rus* as the most dominant species (15.9%), followed by *Acropora robusta* (14.5), *Seriatopora hystrix* (7%), *Lithophyllon repanda* (6.3%) and *Acropora nasuta* (5.8%) (Fig. 2). These 5 species dominated 49.5% of the communities. However, the distribution of each species at the stations suggests that the dominance of *Porites rus* was due to its high dominance at GV South (53.7%), and that of *Acropora robusta* is due to its high dominance at GV North (43.5%), while the other species did not show obvious dominance at any station.

The principal component analysis (PCA) (Fig. 3) and the hierarchical cluster dendrogram of species and stations suggests that each station was mostly characterized by one to three species. Arakaivo had very different community species composition from the other stations. This station was characterized mostly by branching species such as *Acropora* and *Pocillopora*, which were, with *Echinopora gemmacea* and *Galaxea*

Table 1. Average specific richness and diversity at each station. SD: standard deviation

	Richness		Diversity	
	Mean	SD	Mean	SD
Arakaivo	9.067	2.017	0.891	0.097
Velomitahy	5.846	1.994	0.668	0.161
GV North	4.200	1.373	0.551	0.149
GV South	4.692	1.109	0.559	0.120
ANOVA (p-value)	< 0.001		< 0.001	

Table 2. Pairwise comparison between stations. Probability was calculated using the multiple comparison test of Tukey.

	Richness		Diversity	
Comparison	t-value	p-value	t-value	p-value
Arakaivo - Velomitahy	-4.246	< 0.001	-4.433	< 0.001
Arakaivo - GV North	7.270	< 0.001	6.993	< 0.001
Arakaivo - GV South	5.895	< 0.001	6.584	< 0.001
Velomitahy - GV North	2.760	0.0388	2.306	0.110
Velomitahy - GV South	1.594	0.3909	2.079	0.173
GV North - GV South	1.111	0.6846	0.154	0.999

Table 3. List of species recorded during the survey, total abundance, dominance, constancy and fidelity of each species. TA: total abundance (number of recorded individuals); D: dominance (in %); C: constancy (in %); F: fidelity (in %); OD: overall dominance (in %). Dark grey cells with bold font = C or F > 75% ; Grey cells = 50% < C or F < 74.99% ; Light grey cells = 25% < C or F < 49.99% ; White cells = C or F < 25%.

Species	TA	Arakaivo			Velomitahy			GV North			GV South		
		D	C	F	D	C	F	D	C	F	D	C	F
Acropora abrotanoides	5	2	20	**100**									
Acropora branchi	8	3	33.3	**100**									
Acropora clathrata	24	11.6	73.3	**100**									
Acropora cytherea	12	6.2	53.3	**100**									
Acropora digitifera	11	3.4	46.7	**77.8**				2.8	13.3	22.2			
Acropora divaricata	9	1.4	13.3	28.6	1.6	20	42.9	1.7	6.7	14.3	0.6	6.7	14.3
Acropora muricata	19	4	40	60	9.6	26.7	40						
Acropora latistella	6	2.4	33.3	**100**									
Acropora nasuta	45	6.4	60	36	4.7	33.3	20	9.1	40	24	2.9	33.3	20
Acropora robusta	83	5.4	20	13	8.1	26.7	17.4	43.5	**100**	65.2	1	6.7	4.3
Acropora retusa	12	4.9	26.7	57.1				1.4	20	42.9			
Acropora samoensis	13	5.4	53.3	**80**							1.5	13.3	20
Acropora tenuis	5	1.8	13.3	66.7				0.6	6.7	33.3			
Echinopora gemmacea	9	3.4	46.7	**77.8**				0.6	6.7	11.1	0.5	6.7	11.1
Lithophyllon repanda	35	0.6	13.3	9.1	5	40	27.3	15.7	73.3	50	3.7	20	13.6
Galaxea astreata	18				14.5	40	75	0.6	6.7	12.5	0.4	6.7	12.5
Galaxea fascicularis	7	2.8	33.3	**100**									
Goniastrea pectinata	2	0.6	6.7	50	0.4	6.7	50						
Herpolitha limax	8				1.1	20	42.9	4.4	26.7	57.1			
Lobophyllia corymbosa	7				2	13.3	50	1	6.7	25	1.7	6.7	25
Montipora undata	2	0.3	6.7	50	1.7	6.7	50						
Pavona cactus	40				14.9	53.3	72.7				1.9	20	27.3
Pavona clavus	11	0.3	6.7	25	2.2	6.7	25				4.1	13.3	50
Plerogyra sinuosa	29				13.9	60.0	64.3				5.9	33.3	35.7
Pocillopora damicormis	34	12	**93.3**	66.7	0.4	6.7	4.8	3	26.7	19	2.3	13.3	9.5
Pocillopora fungiformis	29	11.6	**80**	**100**									
Pocilopora grandis	8	1.9	20	75				1	6.7	25			
Pocilopora verrucosa	1	0.4	6.7	**100**									
Porites lutea	3	1.1	13.3	66.7							0.8	6.7	33.3
Porites profundus	16	0.4	6.7	9.1	1.7	6.7	9.1				7.8	60	**81.8**
Porites rus	94	1.4	20	11.1	5	40	22.2	3.7	20	11.1	53.7	**100**	55.6
Seriatopora caliendrum	3	0.6	6.7	33.3	1.2	13.3	66.7						
Seriatopora hystrix	49	4.2	53.3	25	8.1	60	28.1	5.8	33.3	15.6	9.9	66.7	31.3
Stylophora madagascarensis	3				1.3	13.3	66.7				1.3	6.7	33.3
Stylophora pistillata	6							3.7	20	**100**			
Stylophora subserata	8	0.6	6.7	16.7	2.6	20	50	1.7	13.3	33.3			

Table 4. Comparative list of genera and number of species of Scleractinia recorded on the coral reefs of the SW region of Madagascar and the present study (Genera in bold font). P: number of species recorded by Pichon (1978), T: number of species recorded by the authors at the selected stations. nr: not recorded.

Genera	P	T	Genera	P	T	Genera	P	T	Genera	P	T
Acropora	13	13	*Dendrophyllia*	2	nr	*Balanophyllia*	1	nr	*Merulina*	1	nr
Pavona	8	2	***Echinopora***	2	1	*Caryophillia*	1	nr	*Montastrea*	1	nr
Fungia	7	1	***Galaxea***	2	2	*Caulastrea*	1	nr	*Oxypora*	1	nr
Pocillopora	7	4	***Goniastrea***	2	1	*Culicia*	1	nr	*Paracyathus*	1	nr
Porites	7	3	*Goniopora*	2	nr	*Cycloseris*	1	nr	*Parascolymia?*	1	nr
Leptoseris	6	nr	*Hydnophora*	2	nr	*Cynarina*	1	nr	*Pectinia*	1	nr
Favites	5	nr	*Mycedium*	2	nr	*Diaseris*	1	nr	*Physogyra*	1	nr
Montipora	5	1	*Oulophyllia*	2	nr	*Diploastrea*	1	nr	*Platygyra*	1	nr
Turbinaria	5	nr	*Pachyseris*	2	nr	*Echinophyllia*	1	nr	*Plerogyra*	1	1
Favia	3	nr	*Platygyra*	2	nr	*Gyrosmilia*	1	nr	*Podabacia*	1	nr
Leptastrea	3	nr	*Plesiastrea*	2	nr	*Halomitra*	1	nr	*Polycyathus*	1	nr
Lobophyllia	3	1	*Turbastraea*	2	nr	***Herpolitha***	1	1	***Seriatopora***	1	2
Psammocora	3	nr	*Acanthastrea*	1	nr	*Heterocyathus*	1	nr	*Siderastrea*	1	nr
Stylophora	3	3	*Agariciclla*	1	nr	*Heteropsamia*	1	nr	*Sphenotrochus*	1	nr
Blastomussa	2	nr	*Alveopora*	1	nr	*Horastrea*	1	nr	*Stylocoeniella*	1	nr
Coscinarea	2	nr	*Anomastrea*	1	nr	*Leptoria*	1	nr	*Symphyllia*	1	nr
Cyphastrea	2	nr	*Astreopora*	1	nr	*Madracls*	1	nr	*Trachyphyllia*	1	nr

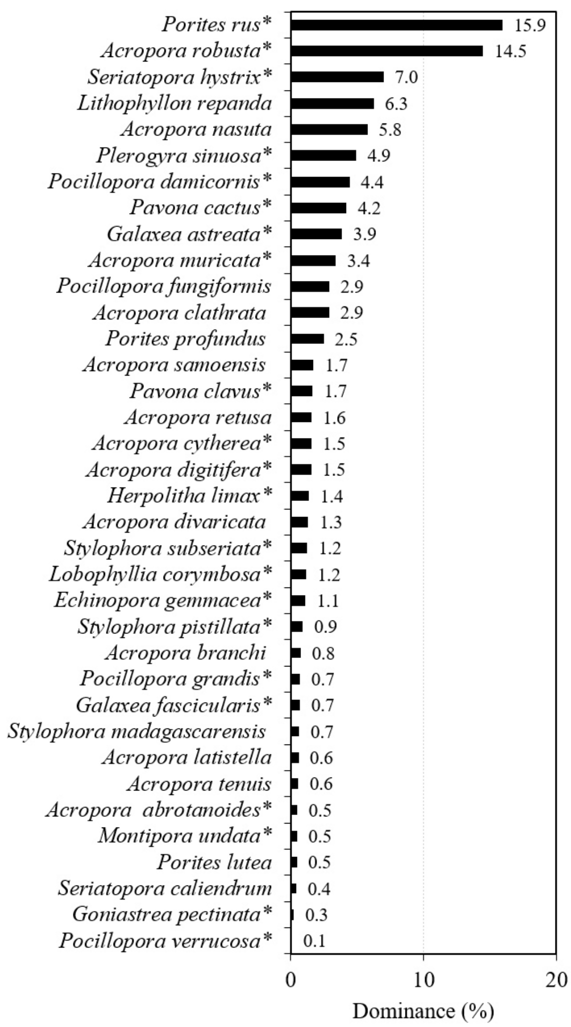

Figure 2. Total dominance of each species. Species followed by * were listed by Pichon (1978), including synonymized species name (WoRMS Editorial Board, 2016).

fascicularis, the less common but the most selective species (Fig. 4). Velomitahy was characterized by less common but indifferent species (Fig. 4a), particularly by *Pavona cactus*, *Plerogyra sinuosa* and *Galaxea astreata*. These species, with the others that are tolerant, are common to the region and recorded from at least 3 of the studied stations (Table 3). GV South was largely characterized by the species *Porites rus* whose dominance influences the whole community at this station. GV North presents a similar community as Velomitahy (Table 3, Fig. 4b). This station was particularly characterized by the free species *Lithophyllon repanda* and *Herpolita limax*, which are also indifferent, according to calculations.

Discussion

Thirty six species from 14 genera and 9 families were recorded at the 4 monitored stations. The scleractinian diversity was relatively low compared to similar studies in the WIO region (e.g. Sheppard, 1987; Beenaerts and Berghe, 2005; Obura, 2012), and especially the study of Pichon (1978) (corrected later by Sheppard, 1998) who observed 112 species belonging to 57 genera on the GRT. The results from the present study may be due to the smaller surface area sampled, compared to Pichon's (1978) study. Apart from the work of Pichon (1978), the only other study on the overall coral biodiversity of the GRT was carried out in the 2000s, and revealed the loss of from 8 to 18 coral

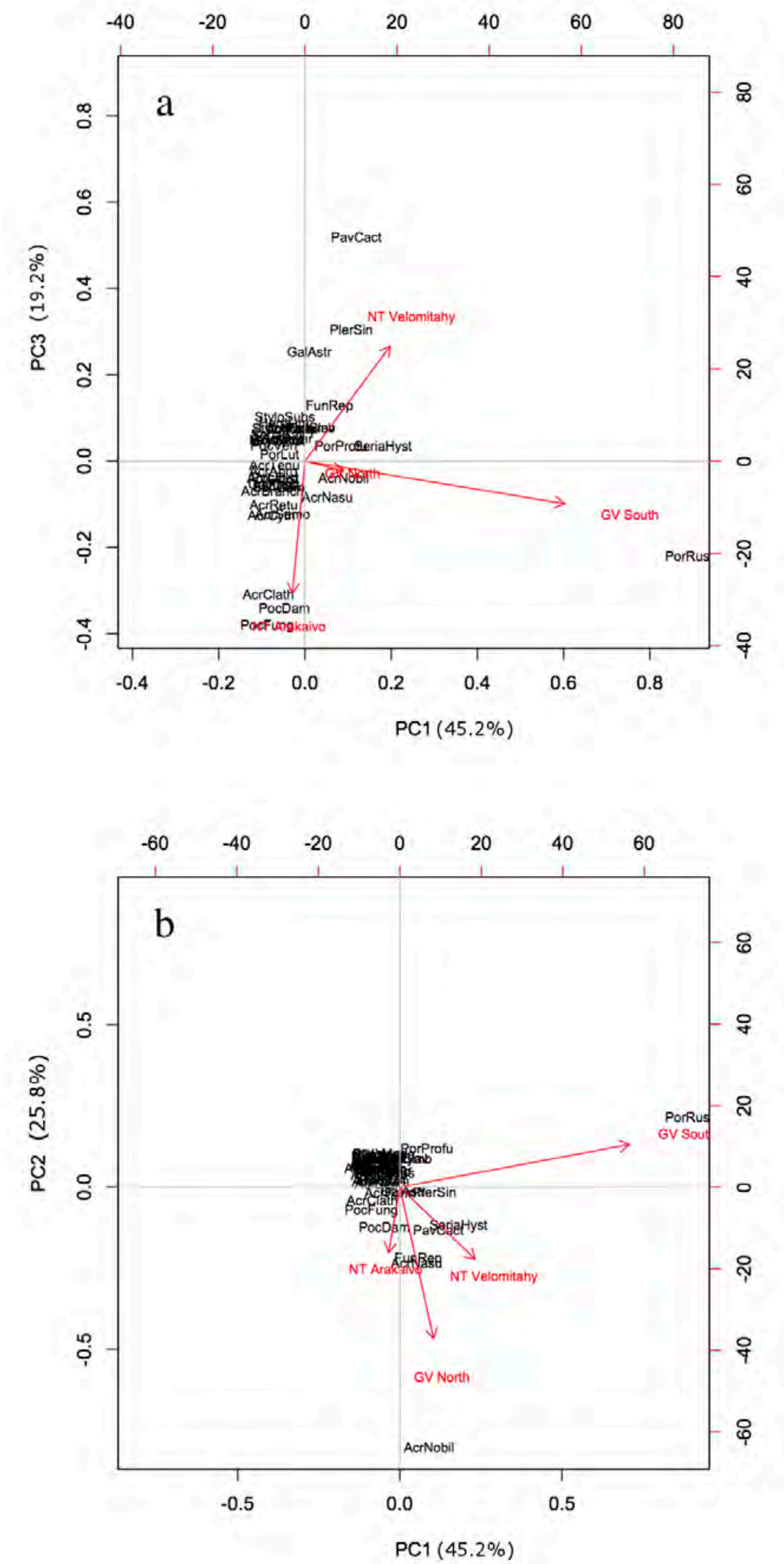

Figure 3. Principal component analysis of the stations and the species; a: according PCA1-PCA3 projection; b: according to the PCA1-PCA2 projection.

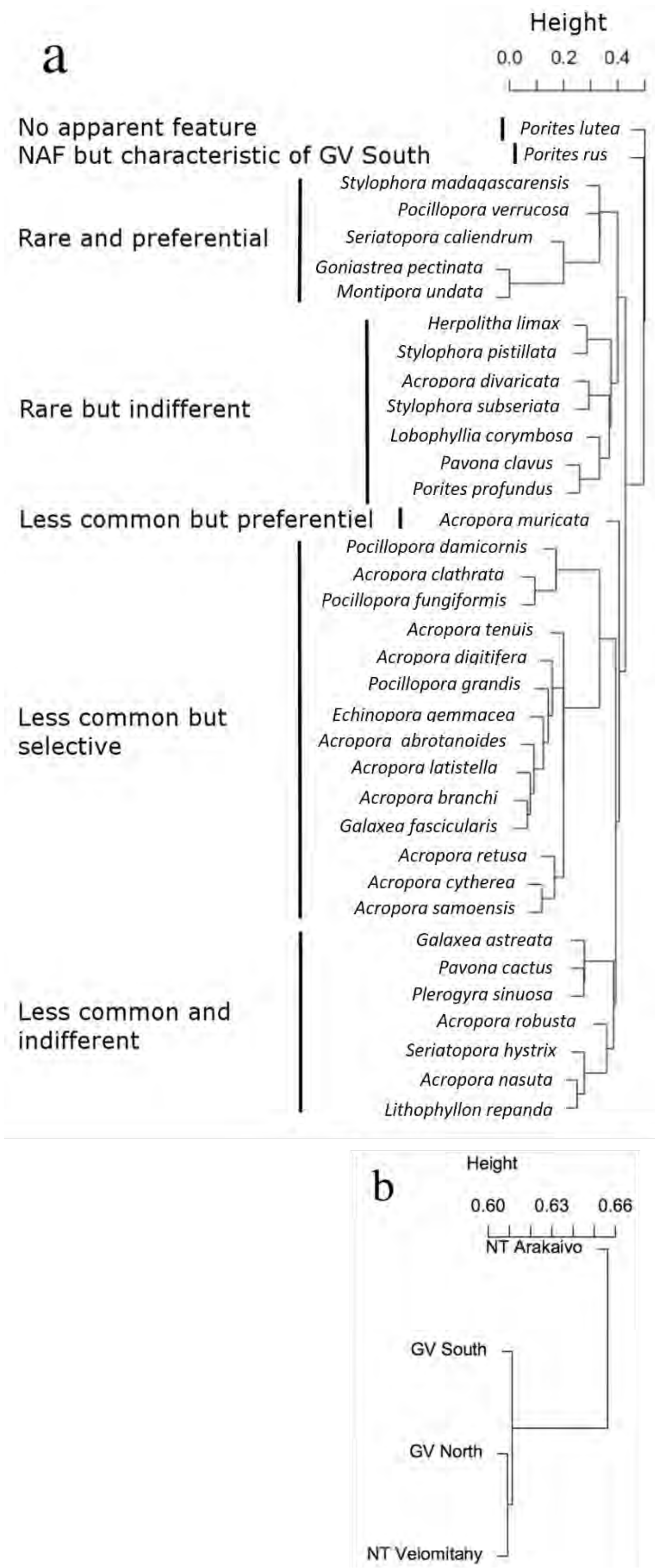

Figure 4. (a) Cluster dendrogram of species, based on their abundance at each station. The characteristics of each group of species are based on the results of constancy and fidelity (Table 3). NAF = No apparent feature; (b) Cluster dendrogram of the stations.

genera (Harris *et al*., 2010; Bruggemann *et al*., 2012). But, as in the present study, this work did not cover all the stations studied in 1978, or in 2008 (by Harris *et al*., 2010) and comparisons with the work conducted 40 years ago are difficult to make.

The present paper reports a total record of only 24.6% of the total number of genera, and 32.1% of the species recorded previously. Most of the genera observed by Pichon (1978) were recorded in the present study, including *Acropora*, *Pocillopora, Stylophora,* and *Porites*. Fourteen of the presently listed species were not listed by Pichon (1978), including eight species of *Acropora* (*A. branchi, A. clathratha, A. divaricata, A. latistella, A. nasuta, A. retusa, A. samoensis*, and *A. tenuis*), two *Porites* (*P. lutea* and *P. profundus*), one *Pocillopora* (*P. fungiformis*), one *Seriatopora* (*S. caliendrum*), one *Stylophora* (*S. madagascariensis*) and one *Lithophyllon* (*L. repanda*). *Lithophyllon* was the least represented with only 1 of 7 species recorded (present study; Pichon, 1978). *Acropora* was well represented in the present study with all 13 species recorded, while only 5 of the 13 were in the list of Pichon (1978).

The richness and diversity at Arakaivo appears very different from the three others staions. Arakaivo is the most exposed station to the water current and it hosts most of the branching species. The richness and diversity at Velomitahy, which is only separated by a few hundred metres from Arakaivo, are closer to those of the GV, a station well protected from the hydrodynamics of the open sea. In the GV, the South is dominated by the species *Porites rus* for an unknown reason, while the diversity of the North of the GV and Velomitahy are very similar. Pichon (1978) differentiated three coral communities according to the depth of the reef slope: many *Acropora* and species of Pocilloporidae inhabit the upper part of the slope; the massive species (e.g. *Pavona*, *Plerogyra* and *Galaxea*) are restricted to the lower part of the slope; and other species like *Porites*, *Montipora* and some *Acropora* occur from the top to the bottom of the slope. In the present paper a zone between 8 to 15 m depths was investigated. Branching colonies were observed in NT and in the GV, but principally at the hydrodynamically active station, Arakaivo. In addition to hydrodynamics, the difference in coral composition between the studied stations could also be explained by the change in habitat structure due to sedimentation and fishing pressure. Indeed, in 50 years, the sedimentation has increased on the GRT and certainly influences the structure of the habitats and consequently the structure of the benthic community, especially the scleractinians (Bruggemann *et al*., 2012; Andréfouët *et al*., 2013). Sheridan *et al*. (2015) showed that the GRT was more affected by diseases than coral reefs of the SW of Madagascar that were not subjected to sedimentation. Except for Arakaivo, the two other stations are highly accessible to fishermen and are the most frequented fishing zones. These stations are subjects to frequent trampling due to destructive fishing techniques (Salimo, 1997). The results from the present study suggest that the GRT scleractinian communities have undergone a significant change in terms of diversity and population structure. Further investigations on this reef, and the management recommendations for its exploitation (small-scale fishery and aquaculture) must consider these changes. In addition, management measures (implementation of protected areas, restoration programmes) must be adapted to ensure greater efficiency.

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