Spatial patterns of coral community structure in the Toliara region of southwest Madagascar and implications for conservation and management

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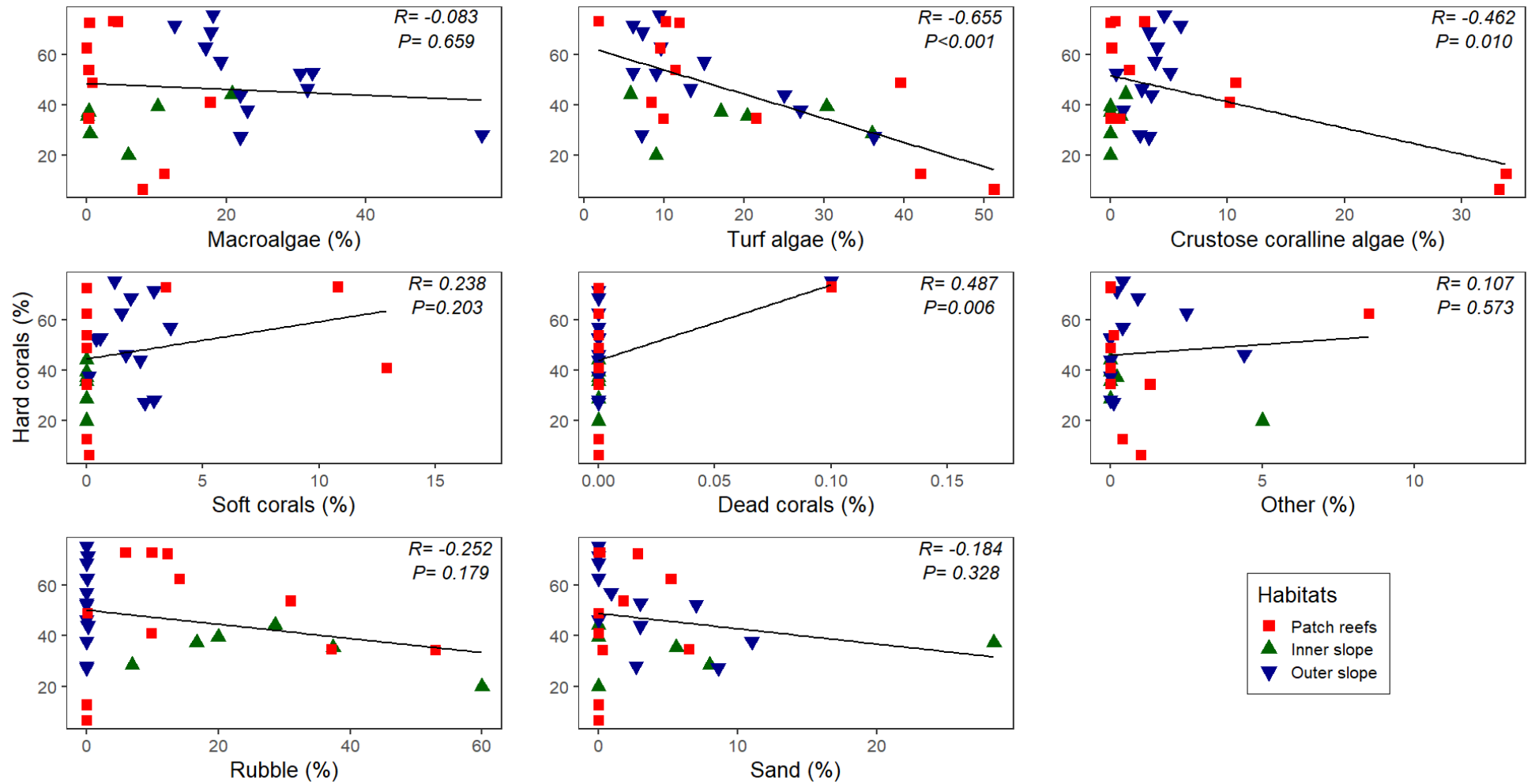
Supplementary Materials

Figure S1. Pearson correlations (R) between spatial distribution of coral cover and all other benthic categories recorded in this study. Correlations were calculated at the transect level.
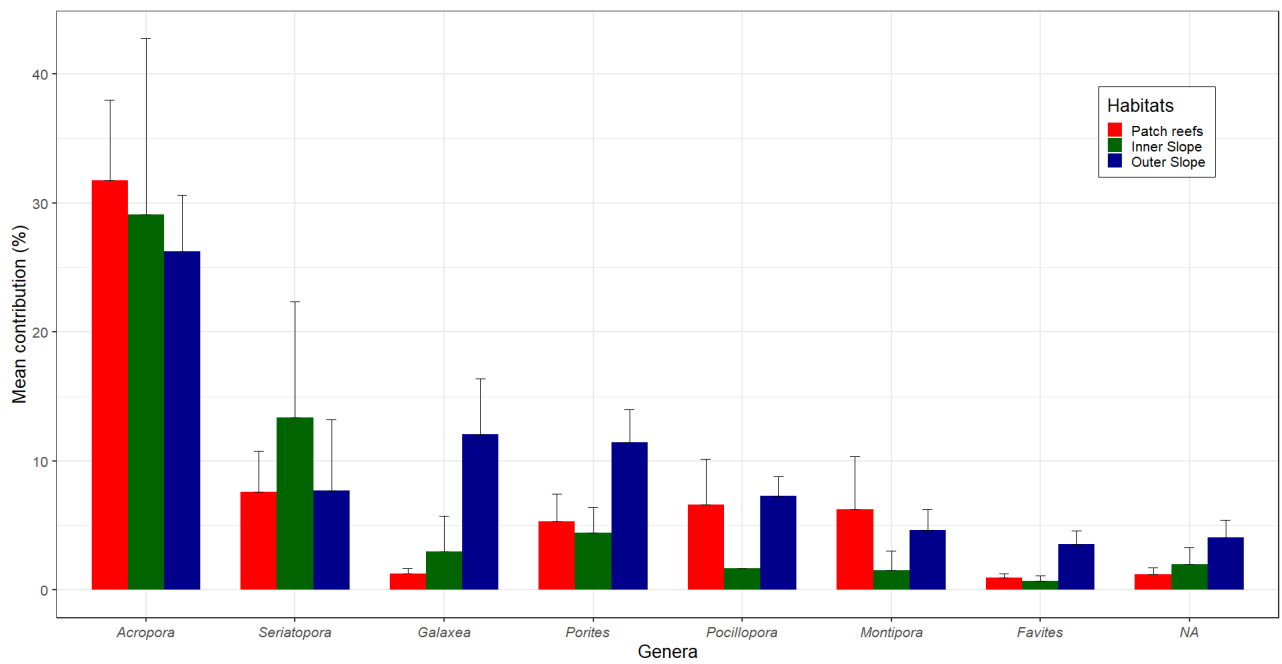
Figure S2. Contribution to the overall coral abundance (expressed in %) of the eight major coral genera at the three major habitats (Patch reefs, Inner slope, and Outer slope). Error bars represent standard error.

Table S1. Main characteristics of the 10 stations surveyed in the Toliara region of southwest Madagascar.

Station codes	Habitat types	Latitude	Longitude	Depth (m)
IS2	Inner slope	23.382817° S	43.639800° E	8
OS2	Outer slope	23.396850° S	43.632750° E	12
OS3	Outer slope	23.426967° S	43.646800° E	10
IS1	Inner slope	23.472720° S	43.687180° E	8
PR3	Patch reefs	23.474595° S	43.723102° E	8
OS4	Outer slope	23.502997° S	43.688823° E	10
PR1	Patch reefs	23.502906° S	43.725132° E	8
PR2	Patch reefs	23.511528° S	43.709762° E	8
PR4	Patch reefs	23.145707° S	43.591147° E	8
OS1	Outer slope	23.162392° S	43.570894° E	7

Table S2. Summary of the nested ANOVA to test for spatial variability in percent cover of benthic categories among habitats and stations. Significant results (p < 0.05) are indicated in bold.

Source of variation	Df	Sum Sq	Mean Sq	F value	P value
Hard corals					
Habitats	2	1299.2	649.6	3.9	**0.036**
Habitats:Stations	7	5608.6	801.2	4.8	**0.002**
Residuals	20	3306.4	165.3		
Macroalgae					
Habitats	2	8.9	4.4	59.0	**<0.001**
Habitats:Stations	7	6.0	0.9	11.3	**<0.001**
Residuals	20	1.5	0.1		
Turf algae					
Habitats	2	2.0	1.0	1.6	0.236
Habitats:Stations	7	46.1	6.6	10.2	**<0.001**
Residuals	20	12.9	0.6		
Crustose coralline algae					
Habitats	2	11.0	5.5	9.4	**0.001**
Habitats:Stations	7	41.5	5.9	10.1	**<0.001**
Residuals	20	11.7	0.6		
Others					
Habitats	2	0.4	0.2	0.3	0.720
Habitats:Stations	7	10.0	1.4	2.3	0.060
Residuals	20	12.3	0.6		
Sand					
Habitats	2	2.8	1.4	2.8	0.080
Habitats:Stations	7	42.9	6.1	12.3	**<0.001**
Residuals	20	10.0	0.5		
Rubble					
Habitats	2	114.6	57.3	81.2	**<0.001**
Habitats:Stations	7	62.5	8.9	12.7	**<0.001**
Residuals	20	14.1	0.7		
Dead corals					
Habitats	2	0.01	0.01	0.9	0.432
Habitats:Stations	7	0.13	0.02	2.7	**0.039**
Residuals	20	0.13	0.01		
Soft corals					
Habitats	2	6.4	3.2	16.4	**<0.001**
Habitats:Stations	7	19.0	2.7	13.9	**<0.001**
Residuals	20	3.9	0.2		

Table S3. Summary of the pairwise *t*-tests to identify differences between significant groups for percent cover of benthic categories. Significant results (p < 0.05) are indicated in bold.

Source of variation	Hard corals	Macroalgae	Turf algae	Crustose coralline algae	Other	Sand	Rubble
Outer slope - Inner slope	**0.008**	**0.006**	0.347	**<0.001**	0.803	0.613	**0.001**
Patch reefs - Inner slope	0.084	0.557	0.748	**0.029**	0.551	0.404	0.089
Patch reefs - Outer slope	0.62	**<0.001**	0.511	0.806	0.619	0.492	**0.001**

Table S4. Summary of the pairwise *t*-tests to identify differences between stations for percent cover of benthic categories. Significant results (p < 0.05) are indicated in bold.

Source of variation	Hard corals	Macroalgae	Turf algae	Crustose coralline algae	Others	Sand	Rubble	Dead corals	Soft corals
IS2 - IS1	0.943	**<0.001**	0.072	0.920	0.363	**<0.001**	0.032	1.000	1.000
OS1 - IS1	0.357	**<0.001**	0.175	0.084	0.259	**0.002**	**<0.001**	1.000	**0.009**
OS2 - IS1	**0.042**	0.056	0.729	**0.034**	0.462	0.590	**<0.001**	1.000	**<0.001**
OS3 - IS1	**0.003**	0.394	0.260	**0.009**	0.827	1.000	**<0.001**	0.130	**0.001**
OS4 - IS1	0.868	0.058	**0.014**	0.069	0.330	**<0.001**	**<0.001**	1.000	**0.005**
PR1 - IS1	**0.007**	**<0.001**	0.516	0.789	0.076	**0.002**	**0.005**	1.000	1.000
PR2 - IS1	**0.016**	0.342	0.092	**0.030**	0.259	0.857	**<0.001**	**0.005**	**<0.001**
PR3 - IS1	0.547	**<0.001**	0.901	0.592	0.690	0.019	0.517	1.000	1.000
PR4 - IS1	0.270	0.127	**<0.001**	**<0.001**	0.757	1.000	**<0.001**	1.000	0.773
OS1 - IS2	0.322	**<0.001**	**0.004**	0.069	0.819	**0.017**	**<0.001**	1.000	**0.009**
OS2 - IS2	**0.036**	**<0.001**	**0.036**	**0.027**	0.109	**<0.001**	**<0.001**	1.000	**<0.001**
OS3 - IS2	**0.003**	**<0.001**	**0.006**	**0.007**	0.263	**<0.001**	**<0.001**	0.130	**0.001**
OS4 - IS2	0.812	**<0.001**	0.436	0.057	0.946	0.158	**<0.001**	1.000	**0.005**
PR1 - IS2	**0.006**	0.640	**0.018**	0.868	**0.011**	**0.022**	0.389	1.000	1.000
PR2 - IS2	**0.013**	**0.003**	**0.002**	**0.024**	0.819	**<0.001**	0.059	**0.005**	**<0.001**
PR3 - IS2	0.501	0.971	0.091	0.525	0.606	**0.002**	**0.008**	1.000	1.000
PR4 - IS2	0.302	**0.012**	**0.014**	**<0.001**	0.545	**<0.001**	**<0.001**	1.000	0.773
OS2 - OS1	0.233	**0.033**	0.305	0.650	0.070	**0.008**	1.000	1.000	0.190
OS3 - OS1	**0.025**	**0.003**	0.809	0.287	0.182	**0.002**	0.714	0.130	0.409
OS4 - OS1	0.448	**0.032**	**0.001**	0.920	0.871	0.271	0.830	1.000	0.782
PR1 - OS1	0.055	**<0.001**	0.466	0.050	**0.007**	0.903	**<0.001**	1.000	**0.009**
PR2 - OS1	0.104	**<0.001**	0.718	0.606	1.000	**0.004**	**<0.001**	**0.005**	**<0.001**
PR3 - OS1	0.745	**<0.001**	0.142	0.217	0.458	0.372	**<0.001**	1.000	**0.009**
PR4 - OS1	0.051	**<0.001**	**<0.001**	**<0.001**	0.406	**0.002**	0.879	1.000	**0.018**
OS3 - OS2	0.245	0.259	0.429	0.534	0.602	0.590	0.714	0.130	0.613
OS4 - OS2	0.059	0.982	**0.006**	0.723	0.096	**0.001**	0.830	1.000	0.295
PR1 - OS2	0.426	**<0.001**	0.760	**0.019**	0.276	**0.006**	**<0.001**	1.000	**<0.001**
PR2 - OS2	0.641	**0.007**	0.171	0.950	0.070	0.719	**<0.001**	**0.005**	**0.001**
PR3 - OS2	0.135	**<0.001**	0.638	0.098	0.262	0.058	**<0.001**	1.000	**<0.001**
PR4 - OS2	**0.004**	**0.002**	**<0.001**	**<0.001**	0.300	0.590	0.879	1.000	**0.001**
OS4 - OS3	**0.005**	0.269	**0.001**	0.333	0.237	**<0.001**	0.879	0.130	0.580
PR1 - OS3	0.705	**<0.001**	0.623	**0.005**	0.115	**0.002**	**<0.001**	0.130	**0.001**
PR2 - OS3	0.478	0.080	0.548	0.576	0.182	0.857	**0.001**	0.130	**<0.001**
PR3 - OS3	**0.012**	**<0.001**	0.213	**0.028**	0.538	0.019	**<0.001**	0.130	**0.001**
PR4 - OS3	**<0.001**	**0.023**	**<0.001**	**<0.001**	0.599	1.000	0.830	0.130	**0.003**
PR1 - OS4	**0.011**	**<0.001**	**0.003**	**0.040**	**0.010**	0.325	**<0.001**	1.000	**0.005**
PR2 - OS4	**0.022**	**0.007**	**<0.001**	0.677	0.871	**<0.001**	**0.001**	**0.005**	**<0.001**
PR3 - OS4	0.661	**<0.001**	**0.018**	0.184	0.560	0.054	**<0.001**	1.000	**0.005**
PR4 - OS4	0.208	**0.002**	0.074	**<0.001**	0.502	**<0.001**	0.950	1.000	**0.010**
PR2 - OS4	0.738	**0.001**	0.280	**0.017**	**0.007**	**0.003**	0.275	**0.005**	**<0.001**

PR3 - OS4	**0.028**	0.615	0.441	0.425	**0.034**	0.313	**0.001**	1.000	1.000
PR4 - OS4	**0.001**	**0.004**	**<0.001**	**<0.001**	**0.041**	**0.002**	**<0.001**	1.000	0.773
PR3 - PR2	0.056	**0.003**	0.072	0.087	0.458	**0.027**	**<0.001**	**0.005**	**<0.001**
PR4 - PR2	**0.001**	0.543	**<0.001**	**<0.001**	0.406	0.857	**0.001**	**0.005**	**<0.001**
PR4 - PR3	**0.013**	**0.013**	**<0.001**	**<0.001**	0.928	**0.019**	**<0.001**	1.000	0.773

Table S5. Summary of the nested ANOVA to test for spatial variability in generic richness among habitats and stations. Significant results (p < 0.05) are indicated in bold.

Source of variation	Df	Sum Sq	Mean Sq	F value	P value
Habitats	2	115.45	57.73	6.21	**0.008**
Habitats:Stations	7	344.42	49.20	5.29	**0.002**
Residuals	20	186.00	9.30		

Table S6. Summary of the pairwise *t*-tests to identify differences between habitats for generic richness. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
Outer slope - Patch reefs	**0.032**
Inner slope - Patch reefs	**0.032**
Inner slope - Outer slope	0.911

Table S7. Summary of the pairwise *t*-tests to identify differences between stations for generic richness. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
PR2 - PR1	**0.034**
PR3 - PR1	**0.003**
PR4 - PR1	0.792
OS1 - PR1	0.297
OS2 - PR1	**<0.001**
OS3 - PR1	**0.045**
OS4 - PR1	**<0.001**
IS1 - PR1	**0.034**
IS2 - PR1	**0.001**
PR3 - PR2	0.297
PR4 - PR2	0.058
OS1 - PR2	0.242
OS2 - PR2	**0.026**
OS3 - PR2	0.895
OS4 - PR2	**0.034**
IS1 - PR2	0.895
IS2 - PR2	0.156
PR4 - PR3	**0.006**
OS1 - PR3	**0.034**
OS2 - PR3	0.196
OS3 - PR3	0.242
OS4 - PR3	0.242
IS1 - PR3	0.297
IS2 - PR3	0.692
OS1 - PR4	0.431
OS2 - PR4	**<0.001**
OS3 - PR4	0.076
OS4 - PR4	**<0.001**
IS1 - PR4	0.058
IS2 - PR4	**0.002**
OS2 - OS1	**0.002**
OS3 - OS1	0.297
OS4 - OS1	**0.002**
IS1 - OS1	0.242
IS2 - OS1	**0.014**
OS3 - OS2	**0.019**
OS4 - OS2	0.895
IS1 - OS2	**0.026**
IS2 - OS2	0.360
OS4 - OS3	**0.026**
IS1 - OS3	0.895

IS2 - OS3	0.124
IS1 - OS4	**0.034**
IS2 - OS4	0.431
IS2 - IS1	0.156

Table S8. Summary of the nested ANOVA to test for spatial variability in overall abundance of coral colonies among habitats and stations. Significant results (p < 0.05) are indicated in bold.

Source of variation	Df	Sum Sq	Mean Sq	F value	P value
Habitats	2	16175.05	8087.53	4.07	**0.032**
Habitats:Stations	7	53072.42	7581.77	3.81	**0.008**
Residuals	20	39771.33	1988.57		

Table S9. Summary of the pairwise *t*-tests to identify differences between habitats for abundance of coral colonies. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
Outer slope - Patch reefs	0.102
Inner slope - Patch reefs	0.592
Inner slope - Outer slope	**0.045**

Table S10. Summary of the pairwise *t*-tests to identify differences between stations for abundance of coral colonies. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
PR2 - PR1	**0.024**
PR3 - PR1	0.070
PR4 - PR1	0.238
OS1 - PR1	0.814
OS2 - PR1	**0.002**
OS3 - PR1	**0.001**
OS4 - PR1	**0.042**
IS1 - PR1	0.094
IS2 - PR1	0.878
PR3 - PR2	0.601
PR4 - PR2	0.234
OS1 - PR2	**0.039**
OS2 - PR2	0.234
OS3 - PR2	0.147
OS4 - PR2	0.786
IS1 - PR2	0.500
IS2 - PR2	**0.033**
PR4 - PR3	0.495
OS1 - PR3	0.109
OS2 - PR3	0.094
OS3 - PR3	0.055
OS4 - PR3	0.800
IS1 - PR3	0.878
IS2 - PR3	0.094
OS1 - PR4	0.339
OS2 - PR4	**0.023**
OS3 - PR4	**0.013**
OS4 - PR4	0.352
IS1 - PR4	0.595
IS2 - PR4	0.301
OS2 - OS1	**0.003**
OS3 - OS1	**0.001**
OS4 - OS1	0.068
IS1 - OS1	0.144
IS2 - OS1	0.935
OS3 - OS2	0.779
OS4 - OS2	0.149
IS1 - OS2	0.070
IS2 - OS2	**0.002**
OS4 - OS3	0.089
IS1 - OS3	**0.040**

IS2 - OS3	**0.001**
IS1 - OS4	0.685
IS2 - OS4	0.058
IS2 - IS1	0.125

Table S11. Summary of the ANOSIM for pairwise comparison in the composition and abundance of coral genera between habitats.

Global test					
Sample statistic (Global R): 0.606					
Significance level of sample statistic: 0.6%					
Number of permutations: 999 (Random sample from 1575)					
Number of permuted statistics greater than or equal to Global R: 5					
Pairwise Tests					
Groups	R	Significance level %	Possible permutations	Actual permutations	Number ≥ Observed
Inner slope - Outer slope	0.857	6.7	15	15	1
Inner slope - Patch reefs	0.071	46.7	15	15	7
Outer slope - Patch reefs	0.688	2.9	35	35	1

Table S12. Composition and abundance (mean number of colonies per station) of coral assemblages at the 10 stations used for nonmetric multidimensional scaling (nMDS).

	IS1	IS2	OS1	OS2	OS3	OS4	PR1	PR2	PR3	PR4
Acanthastrea	0	0	8	2	0	19	0	2	3	1
Acropora	44	56	80	208	359	101	116	160	0	87
Astrea	0	0	0	1	0	4	0	2	0	0
Astreopora	0	0	22	35	24	0	0	0	0	0
Blastomussa	0	0	3	0	0	4	0	0	0	0
Coscinaraea	0	0	11	4	0	15	0	3	3	1
Cycloseris	30	0	2	2	0	0	9	31	85	90
Cyphastrea	5	0	4	0	0	10	1	1	2	8
Diploastrea	0	0	0	0	0	0	0	1	0	0
Dipsastraea	2	12	30	48	2	49	0	12	3	3
Echinophyllia	0	0	0	0	0	1	0	2	1	0
Echinopora	12	1	7	21	11	17	1	2	4	11
Euphyllia	0	0	0	0	0	0	0	2	0	0
Favites	1	4	22	40	5	50	3	2	2	2
Fungia	2	53	1	9	1	6	2	14	2	6
Galaxea	2	1	37	104	238	35	6	10	2	0
Gardineroseris	0	2	6	0	6	6	0	1	0	7
Goniastrea	2	1	5	17	0	7	0	0	3	2
Goniopora	1	1	3	0	3	4	0	3	0	0
Halomitra	0	0	0	0	0	0	1	2	0	0
Herpolitha	0	3	0	1	0	0	1	1	0	0
Hydnophora	9	0	15	29	3	8	1	0	3	0
Leptastrea	1	0	6	6	0	13	0	2	1	0
Leptoria	0	1	0	16	9	8	0	1	0	0
Leptoseris	0	0	0	0	1	0	0	0	0	0
Lobophyllia	0	0	1	0	1	1	0	7	7	0
Merulina	0	3	0	0	0	0	0	2	1	0
Millepora	0	15	0	12	6	0	3	0	0	0
Montipora	9	0	35	38	2	33	3	10	18	1
Mycedium	1	0	0	0	0	0	0	0	0	0
Oulophyllia	0	0	0	6	0	5	0	1	0	0
Pavona	30	85	12	4	2	10	11	4	28	55
Physogyra	0	2	0	0	0	5	0	1	0	0
Platygyra	3	0	14	32	2	29	0	3	9	0
Plerogyra	0	2	6	0	0	9	1	5	1	0
Plesiastrea	0	0	1	0	0	1	0	0	0	0
Pocillopora	5	6	47	75	27	51	2	23	13	55
Podabacia	0	1	0	1	0	0	0	0	0	0
Porites	19	9	95	123	38	23	0	2	10	0
Psammocora	3	0	8	2	0	20	0	10	4	1
Seriatopora	5	81	1	63	229	3	30	75	30	1
Stylophora	9	23	3	9	8	1	18	16	31	16
Turbinaria	0	0	4	3	0	1	0	0	0	0

Table S13. Summary of the ANOVA per permutation for comparison of the size frequency distribution among each habitat based on the colony abundances. Significant results (p < 0.05) are indicated in bold.

Source of variation	Df	R Sum Sq	R Mean Sq	Iter	P value
Habitats	2	29318	14658.8	5000	**0.001**
Size classes	5	127345	25469	5000	**0.001**
Habitats × Size classes	10	33564	3356.4	5000	**0.001**
Residuals	162	163297	1008		

Table S14. Summary of the pairwise *t*-test of the size frequency distribution between habitats based on the colony abundances. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
Outer slope - Inner slope	**0.006**
Patch reefs - Inner slope	0.414
Patch reefs - Outer slope	**0.006**

Table S15. Summary of the pairwise test of the size frequency distribution based on the colony abundances. Significant results (p < 0.05) are indicated in bold.

Source of variation	P value
[11-20]-[6-10]	**0.012**
[11-20]-[21-40]	**0.002**
[11-20] - [41-80]	**0.002**
[11-20] - [81-160]	**0.002**
[11-20] - [161-320]	**0.002**
[21-40]-[41-80]	**0.017**
[21-40]-[6-10]	0.068
[21-40]-[81-160]	**0.002**
[6-10]-[81-160]	**0.002**
[41-80]-[6-10]	**0.002**
[41-80]-[81-160]	**0.002**
[161-320]-[21-40]	**0.002**
[161-320]-[41-80]	**0.002**
[161-320]-[6-10]	**0.002**
[161-320]-[81-160]	**0.017**

Table S16. Coral genera (scleractinians and the calcareous hydrocoral *Millepora*) recorded in the Toliara region of southwest Madagascar in 2017 (present study) and in 1961-1970 (Pichon 1978), in the Andavadoaka region (Harding et al. 2006), in the northwest region by Veron & Turak (2003), and in the northeast region by Obura et al. (2011). A species list of scleractinian corals recorded at Toliara has been published by Todinanahary et al. (2018).

Regions	SW Madagascar	SW Madagascar	SW Madagascar	NW Madagascar	NE Madagascar
Sites	Toliara	Toliara	Andavadoaka		
Sampling periods	2017	1961-1970	2005	2002	2010
References	Present study	Pichon (1978)	Harding et al. (2006)	Veron & Turak (2003)	Obura et al. (2011)
Acanthastrea	√	√	√	√	√
Acropora	√			√	√
Agariciella		√			
Alveopora		√		√	√
Anacropora				√	√
Anomastraea		√		√	√
Astrea	√	√	√	√	√
Astreopora	√	√	√	√	√
Balanophyllia		√			
Barabattoia					√
Blastomussa	√	√	√	√	
Cantharellus				√	
Catalaphyllia				√	√
Caulastrea		√	√	√	√
Coeloseris				√	√
Coscinaraea	√	√	√	√	√
Craterastrea			√		
Ctenella				√	
Cycloseris	√	√	√	√	√
Cynarina		√		√	√
Cyphastrea	√	√	√	√	√
Dendrophyllia		√			

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Diaseris		√		√	√
Diploastrea	√	√	√	√	√
Dipsastraea	√	√	√	√	√
Echinophyllia	√	√	√	√	√
Echinopora	√	√	√	√	√
Euphyllia	√			√	√
Favites	√	√	√	√	√
Fungia	√	√	√	√	√
Galaxea	√	√	√	√	√
Gardineroseris	√		√	√	√
Goniastrea	√	√	√	√	√
Goniopora	√	√	√	√	√
Gyrosmilia		√	√	√	√
Halomitra	√	√	√	√	√
Herpolitha	√	√	√	√	√
Heterocyathus		√			√
Heteropsammia		√		√	√
Horastrea		√	√	√	√
Hydnophora	√	√	√	√	√
Leptastrea	√	√	√	√	√
Leptoria	√	√	√	√	√
Leptoseris	√	√	√	√	√
Lithophyllon			√		
Lobophyllia	√	√	√	√	√
Madracis		√		√	√
Merulina	√	√	√	√	√
Micromussa					√
Millepora	√	√	√	√	√
Montipora	√	√	√	√	√
Mycedium	√	√	√	√	√
Nemenzophyllia			√		
Oulophyllia	√	√	√	√	√

Oxypora		√	√	√	√
Pachyseris		√	√	√	√
Parascolymia		√			
Pavona	√	√	√	√	√
Pectinia		√	√	√	√
Physogyra	√	√	√	√	√
Platygyra	√	√	√	√	√
Plerogyra	√	√	√	√	√
Plesiastrea	√		√	√	√
Pocillopora	√	√	√	√	√
Podabacia	√	√	√	√	√
Polyphyllia				√	√
Porites	√	√		√	√
Poritipora			√	√	√
Psammocora	√	√	√	√	√
Pseudosiderastrea				√	√
Sandalolitha					
Scolymia		√	√	√	√
Seriatopora	√	√	√	√	√
Siderastrea		√	√	√	√
Stylaraea				√	√
Stylocoeniella		√	√	√	√
Stylophora	√	√	√	√	√
Symphyllia				√	√
Trachyphyllia		√		√	√
Tubastrea		√	√		
Turbinaria	√	√	√	√	√
Total	43	61	54	69	69

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