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CAN ORGANISMS ASSOCIATED WITH LIVE SCLERACTINIAN CORALS BE USED AS INDICATORS OF CORAL REEF STATUS?

BY

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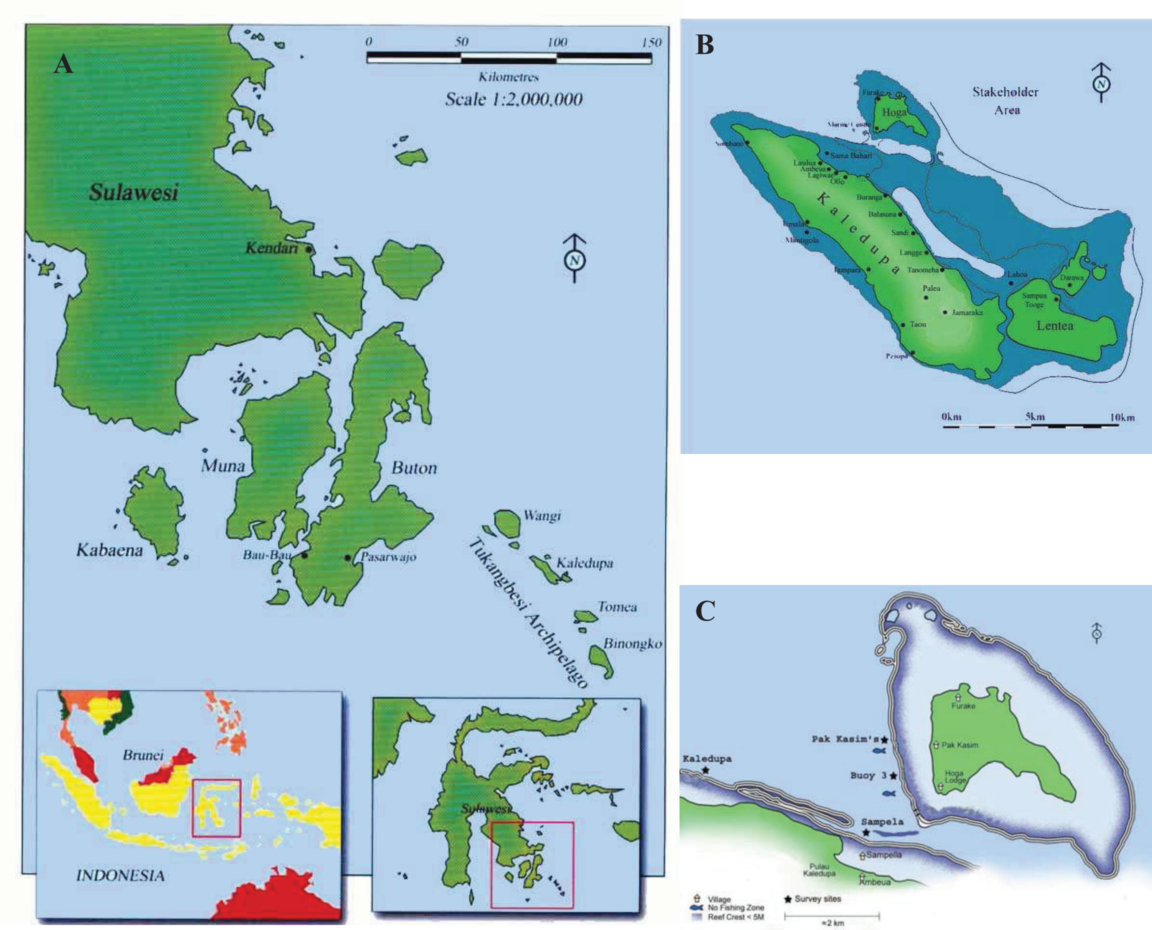

Figure 1. (A) Hoga and (B) Kaledupa islands in the Tukang Besi Archipelago and (C) location of the survey sites.

CAN ORGANISMS ASSOCIATED WITH LIVE SCLERACTINIAN CORALS BE USED AS INDICATORS OF CORAL REEF STATUS?

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PATRICK SCAPS [1*] AND VIANNEY DENIS[1§]

ABSTRACT

With the intention of knowing if coral associates can be used as indicators of coral reef status, we studied organisms associated with live scleractinian corals on different sites located around Hoga and Kaledupa islands in the Tukang Besi Archipelago of the south-eastern coast of Sulawesi in the Banda Sea, in Indonesia. Twenty meter long line intercept transects were used to estimate the number of coral colonies infested by coral associates. The number of coral associates found on each coral colony on the transect was recorded and corals were identified to the most precise level. Massive and encrusting coral colonies were also measured in order to estimate the densities of infestation per square meter of coral colonies. To link the assemblages of coral associates observed with the characteristics of the benthic habitats, the coral cover was estimated using a 0.5 m point intercept transect method.

Three hundred seventy-six colonies (45%) were infested by a total of 2,815 coral associates. In total, coral associates amounted to 2,062 lithophagid bivalves (73% of total coral infestations), 306 dwelling hermit crabs of the genus *Paguritta* (10.9%) and 242 vermetid snail *Dendropoma maxima* (8.6 %). The most infested colonies belonged to the genera *Montipora*, *Pavona* and *Porites*. They represented 33%, 23% and 18% of the total number of colonies infested respectively. The highest densities of infestation were found for the boring *Lithophaga* spp. for which a density of 88 ind/m2 was noticed in encrusting corals of the genus *Pavona*.

The density of lithophagid bivalves and the number of infested colonies were high in the most impacted site (Sampela) and one of the intermediately impacted site (Pak Kasim's) whereas they were low in the most pristine site (Kaledupa). The other intermediately impacted site (Buoy 3) had an intermediate number of infestations. Despite the lack of any significant difference in biotic cover between the most pristine site and the intermediately impacted sites, a common gradient tends to emerge based on coral associates. Although having a high biotic cover, Pak Kasim's suffers from a similar level of infestation as Sampela suggesting process of reef degradation previously experienced by the most impacted site. Our results suggest that coral associates can be used as indicators of coral reef status.

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INTRODUCTION

Living scleractinian corals provide microhabitats for a large number of parasitic and commensal coral associates which use the tissue and skeleton of the coral colonies as substrata (Frank et al., 1995; Floros et al., 2005). Coral associates are defined as sessile invertebrates that live on or within the coral skeleton (Risk et al., 2001) and whose apertures open through the living coral tissue (Scott, 1987). Many taxa are involved, including sponges, polychaetes, bivalves, tunicates and hydroids (reviewed in Scott and Risk, 1988). Most of these coral associates stress the coral to some degree, and some of them, particularly some sponges, polychaetes and bivalves can do considerable harm, at least to the skeleton (Sammarco and Risk, 1990; Smith and Harriott, 1988; Floros et al., 2005).

Almost all coral associates are filter-feeding heterotrophs, hence would be expected to increase in numbers in water with elevated nutrient concentrations (Risk et al., 2001; Floros et al., 2005). In consequence, as suggested by Risk et al. (2001), the health of a reef may be evaluated by scouring the density of coral associates on massive corals. This is based on the theory that coral associate numbers will increase with organic loading: stressed corals will be less able to protect themselves from settlement and overgrowth (Risk et al., 1993).

To date, little attention has been paid to the associates of living corals in Indonesia although this country lies within the triangle of biodiversity harbouring the most biologically diverse coral reefs in the world. So, the goal of this study was to document the community structure of coral asssociates and to link the different assemblages of coral asssociates on reefs around Hoga and Kaledupa islands in Indonesia with the health of these reefs.

STUDY SITES AND METHODS

This study was conducted on the reefs around the islands of Hoga and Kaledupa in the Tukang Besi Archipelago of the south-eastern coast of Sulawesi in the Banda Sea, in Indonesia (Elliot et al., 2001) (Fig. 1A and 1B). This area is considered extremely important for global diversity, evolutionary biology and biogeography. Both islands are located in the Wakatobi Marine National Park (MNP) where a Marine Research Station run by Operation Wallacea is situated (Dioum, 2000). The Wakatobi MNP was established in 1996 and contains approximately 50,000 ha of coral reefs for a total area of about 1.39 million hectares.

A Rapid Ecological Assessment conducted in the Wakatobi MNP in May 2003 (Pet-Soede and Erdmann, 2003) recorded 396 species of hermatypic scleractinian corals belonging to 68 genera and 15 families. In addition, 10 species of non-scleractinian or ahermatypic hard coral species and 28 soft coral genera were added to this list. Despite relatively low diversity of habitat type visited, coral species diversity was relatively high. This is an indication of Wakatobi's position near the center of high coral biodiversity or "Coral Triangle". The three major causes of degradation recorded in the Wakatobi MNP are: bomb fishing, crown-of-thorns starfish proliferation and bleaching (Turak, 2003).

The study took place in July and August 2005 with the help of volunteers and different scientists working for Operation Wallacea. Four sites were studied (Fig. 1C) and were selected with a gradient of degradation according to former investigations led by Operation Wallacea during the previous years (Crabbe and Smith, 2002 ; Crabbe and Smith, 2003) and visual observations conducted in the beginning of the study.

Site Descriptions

Table 1 provides information of the GPS position and the environmental characteristics of the different selected sites. The first site (Kaledupa, Buoy 1), close to the island of Kaledupa, was considered to be in pristine condition (Crabbe and Smith, 2002) and to have no obvious anthropogenic or sedimentation damage. The second site, Sampela, is located within proximity to the Bajo village of Sampela. This site was considered to be extensively impacted (Crabbe and Smith, 2002). There was, notably, a significantly higher hard corals species richness at Kaledupa than at Sampela. The two other sites, Buoy 3 and Pak Kasim's, were considered to be intermediately impacted. Buoy 3 is located in a 1 km-long Non Fishing Zone (NFZ). Pak Kasim's is the closest site from the non-fishing area.

Table 1. GPS position and characteristics of the different sites (* means that the difference with the other sites is signifiant, $p<0.01$).

	Kaledupa	**Sampela**	**Pak Kasim's**	**Buoy 3**
Latitude South	05°28'22"	05°29'01"	05°27'569"	05°28'40"
Longitude East	123°43'47"	123°45'08"	123°45'179"	123°45'45"
Rugosity	0.56 (0.08) N=25	0.73 (0.10)* N=15	0.58 (0.15) N=25	0.60 (0.19) N=23
Sedimentation rate Average of means (g d.wt.$m^{-2}.d^{-1}$)	5.21 (1.01) N= 8	20.46 (2.12)* N= 9	7.25 (0.28) N= 6	
Light attenuation coefficient (K)	0.16 (0.01) N =5	0.24 (0.01) N = 4	0.12 (0.01) N = 5	0.13 (0.01) N = 5

The chain method, which gives an indication on the reef complexity, showed a significant difference for the rugosity at Sampela (ANOVA One-Way, F=4.74, $p<0.01$) (Table 1). This method was performed using a chain laid over the substrata over five replicate sections of each transect. The straight-line distance occupied by the chain was measured, and the rugosity index calculated by dividing the total length of chain by the straight-line distance (McCormick, 1994). The sedimentation rate was measured using sediment traps at three locations at each site (Buoy 3 and Pak Kasim's are considered as the same site as "Hoga" for the measurements of sedimentation rate). Table 1 shows the average of the means for these locations. An analysis of the variance shows a higher sedimentation rate at Sampela than at the other sites (ANOVA One Way, F=24.2,

$p<0.01$).The measurements of turbidity, corresponding to the amount of suspended sediment and plankton in the water column, was assessed using a Secchi disk and the measurements of the light attenuation coefficient (K), agreed to the results obtained by sediment traps and showed higher turbidity in Sampela.

The salinity and the temperature were assessed at two depths (3 and 12 meters) and were relatively constant during the entire study period, whether between the different sites and between the two depths. The seawater temperature varied between 27 and 28°C and the salinity ranged from 32 to 33‰. The maximal tidal range on Hoga is 2 meters but is typically 1.5 meters.

Survey Method

After the characterization of the sites, the study consisted of the selection of the macrobioeroder and coral predator organisms that were among the most common in the reefs around the islands. The majority of bioeroders are not immediately visible on the exterior and it has been suggested that their numbers and combined mass equal or exceed that of the surface biota (Kleemann, 2001). However, for reasons of convenience and adoption of a non-destructive method, only their visible parts were taken into account and studied. Moreover, due to the restrictions on coral sampling which do not allow close examination for sponge invasions, sponges boring in live corals were not studied. Observations conducted during the initial dives at the different sites led to a selection of nine groups of macrobioeroder or coral predator organisms. All these groups (see Table 2) are composed of organisms, which either carry out a bioeroder activity or are predators of living scleractinian corals with an activity sometimes considered more similar to grazing than to bioeroding. Due to problems in identifying the animals, apart from a few exceptions, the different groups were not identified to species level. Coral associates can be classified into two groups: endolithic bioeroders living within the coral skeletons and epilithic organisms living and feeding directly on exposed surfaces. Their activity can be of various intensities depending on the group considered. For example, the serpulid annelid *Spirobranchus giganteus corniculatus* can have a bioerosion rate reaching 1800 g of $CaCO_3$ per square meter by year (Glynn, 1997). The bioerosion rate of the boring bivalves of the genus *Lithophaga* can reach 9000 g $CaCO_3/m^2/yr$ with a density sometimes reaching 1879 ind/m^2 (Glynn, 1997). The dwelling hermit crabs of the genus *Paguritta* can live either in polychaete tubes associated with hard corals (Schumacher, 1977; Miyake, 1978) or other adapted holes, without important bioerosive activity in this case but proof of an active past bioerosion; or in self-created boreholes in living corals (Lewinsohn, 1978) which can lead to significant bioerosion, depending on its density.

The number of coral colonies infested by coral associates was estimated along a 20 m long Line Intercept Transect (LIT) (English et al., 1997) at two different depths (6 m and 12 m). The first transect was laid randomly and the position of the following transects was based on the first one. Each transect was spaced by a gap of approximately 20 meters. For Pak Kasim's and Buoy 3, three transects were deployed and surveyed at both depths. Only the upper part of the reef of Sampela was assessed because the environment at 12 meters consisted of a sandy slope and was devoid of corals. In consequence, only three transects were surveyed at 6 meters. Moreover, due to the heterogeneity of the habitat in Kaledupa in comparison with the other sites, more replicates were assessed for this site. Thus, five transects were deployed and surveyed at each depth.

The number of macrobioeroders and coral predators found on each coral colony on the transect was recorded and corals were identified to the most precise level. Massive and encrusting coral colonies were also measured in order to estimate the densities of infestation per square meter of coral colonies. The infestations were quantified with consideration of the species, and the locations and depths of the sites.

Table 2. Major groups of macrobioeroders and coral predators found in the reefs during this study and their corresponding ecology.

Group	**Ecology**
Mollusca	
Gastropoda	
1. *Coralliophila neritoidea (*Lamarck, 1816) (Plate 1A)	Corallivore
2. *Dendropoma maxima* (Sowerby, 1825) (Plate 1D)	Excavater
3. *Drupella cornus* (Röding, 1798) (Plate 1B)	Corallivore
4. *Serpulorbis grandis* (Gray, 1850)(Plate 1C)	Excavater
Bivalvia	
5. *Arca ventricosa* Lamarck, 1819 (Plate 2E)	Borer
6. *Lithophaga* spp. (Plates 2 A, 2B and 2C)	Borers
7. Pedum spondyloideum (Gmelin, 1791) (Plates 1F, 2C)	Borer
Other bivalvia (*Gastrochaena* spp., (Plate 2D) *Modiolus philippinarum* (Plates 1G, 2B, 2C and 2E) , *Barbatia foliata* (Plate 1E).	Borers
Annelida – polychaeta	
8. *Spirobranchus giganteus corniculatus* (Grube , 1862) (Plate 2F)	Borer and excavater
Crustacea	
9. *Paguritta* spp.	Excavaters

Link with Coral Reef Status

The living conditions of macrobioeroder and coral predator organisms as well as the link between their presence and the state of the coral habitat were analysed. Firstly, their distributions were linked with measured environmental parameters and the characteristics of the different studied sites. Then, to link the assemblages of macrobioeroders and coral predators observed with the characteristics of the benthic habitats, the coral cover was estimated using monitoring methods to assess the reef health. To describe the cover of the major functional groups and dominant coral taxa, a

Plate 1. Organisms associated with live scleractinian corals. (A.) *Coralliophila neritoidea*; (B.) *Drupella cornus*; The vermetid gastropods *Dendropoma maxima* (C.) and *Serpulorbis grandis* (D); (E.) The bivalve *Barbatia foliata*; (F.) The scallop *Pedum spondyloideum*; (G.) The mytilid bivalve *Modiolus philippinarum*.

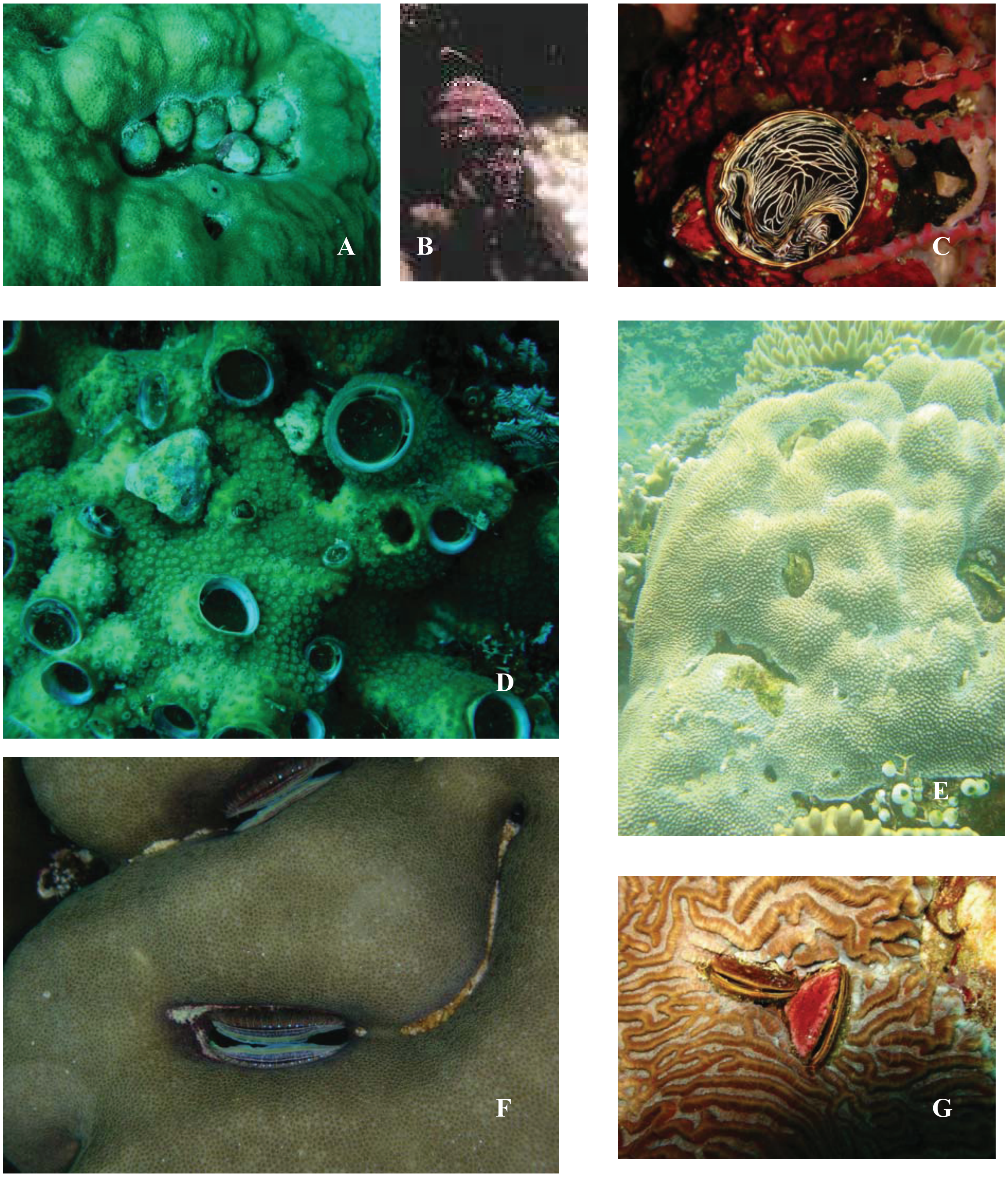
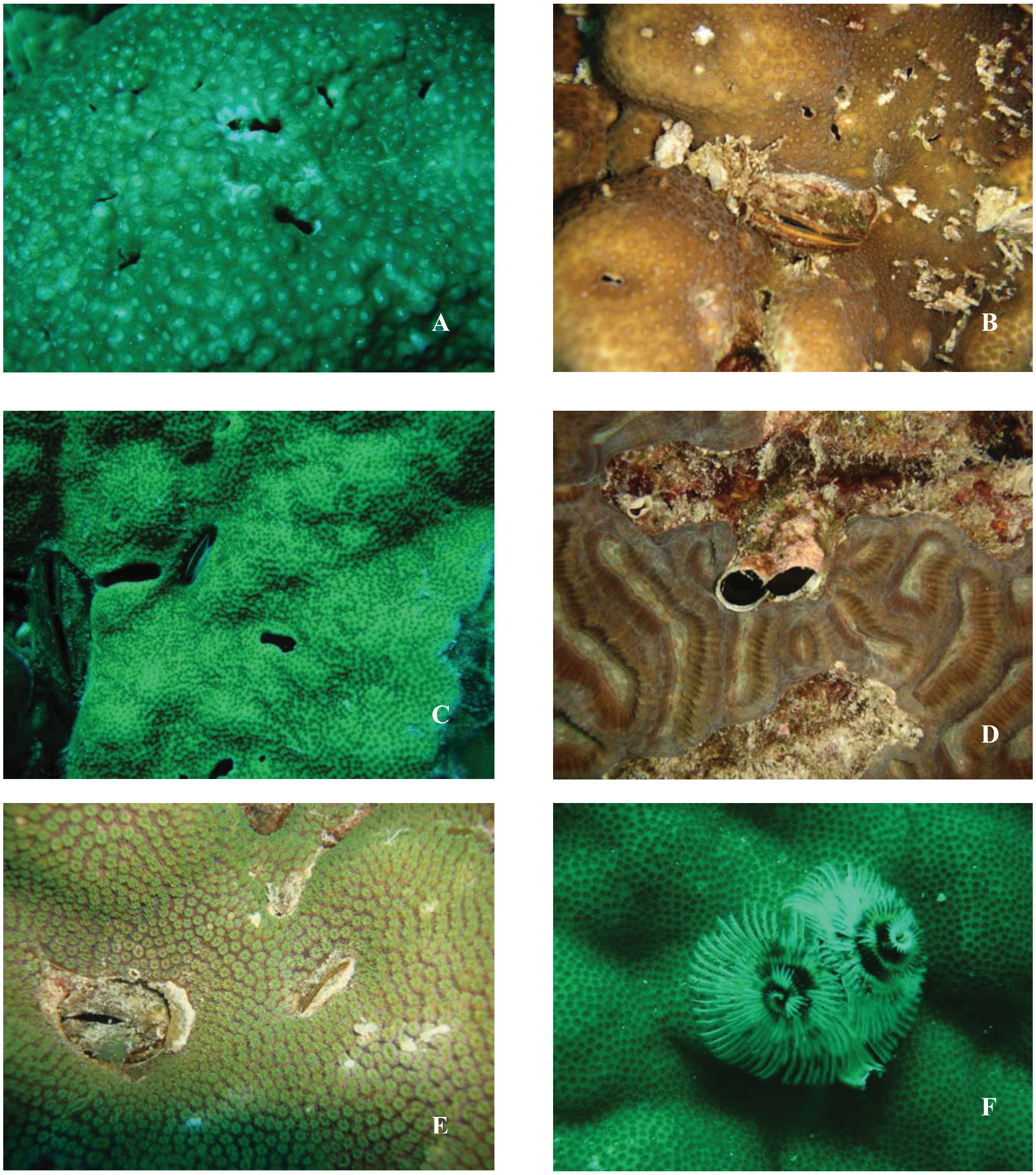


Plate 2. Organism associated with live scleractinian corals. (A.) Boring's openings of dumbbell outline at the surface of a coral colonie of the bivalves *Lithophaga* spp.; (B.) The mussel *Modiolus philippinarum* and boring's openings of *Lithophaga* spp.; (C.) *Modiolus philippinarum*, *Pedum spondyloideum* and boring's openings of lithophagid bivalves; (D.) Boring's openings with narrow siphon tubes of *Gastrochaena* spp.; (E.) *Arca ventricosa* and Modiolus philippinarum; (F.) The Christmas tree worm *Spirobranchus giganteus corniculatus*.



0.5 m Point Intercept Transect (PIT) method (English et al., 1997) was used on the same 20 m-long transect as the macroinvertebrate survey. To support this method, comparisons with datasets obtained from 50 m-long PIT (interval of 0.5 meter) were performed. No significant difference was found, which is a proof of a relative homogeneity of the benthic cover for these stations. Therefore, a 20 m-long PIT could be used in order to maximise the number of replicates.

In addition, a dataset on the presence of "keystone species", such as *Acanthaster planci* or *Diadema* spp., which may have important ecological impacts on the reef was used to complete the analysis.

Statistical Analyses

Statistical analyses were performed with Minitab for parametrical and non-parametrical statistics. PRIMER v6 (Plymouth Marine Laboratory, Clarke and Warwick, 2001) was used for analysis of community. Cochran tests were used to test for homogeneity of variances before ANOVA. Turkey's pairwise comparisons were used for post hoc comparisons. ANOSIM were performed to analyse similarities between sites after the ordinations (Multidimensional Scaling, MDS).

RESULTS

A total of 831 scleractinian coral colonies belonging to 39 genera was recorded during this study. A colony was considered infested when at least one of the studied organisms was found in the coral colony. Three hundred seventy-six colonies (45%) were infested by a total of 2,815 coral associates.

In total, coral associates amounted to 2,062 lithophagid bivalves (73% of total coral infestations), 306 dwelling hermit crabs of the genus *Paguritta*(10.9%) and 242 vermetid snail *Dendropoma maxima* (8.6 %) (Fig. 2 a and b). Other coral associates were less numerous and their contribution to total coral infestations were negligible (less than 3%).

Infestation Rate by Scleractinian Coral Genus

The most infested colonies belonged to the genera *Montipora*, *Pavona* and *Porites* (Fig. 3a). They represented 33%, 23% and 18% of the total number of colonies infested respectively (Fig. 3b). These genera are also those that are the most common on the transects (Fig. 3c); the other genera representing less than 10 % of the total number of infested colonies (Fig. 3b).

The densities of infestation per square meter for massive and encrusting coral colonies are reported in Table 3. The highest densities of infestation were found for the boring *Lithophaga* spp. for which a density of 88 ind/m^2 was noticed in encrusting corals of the genus *Pavona.* Densities per square meter and per colony were positively correlated. For each of the studied group of organisms, the same trend was observed. For example, for the lithophagid bivalves, a positive correlation was noticed between the number of organisms per colony and per square meter of colony (R=0.871, p=0.01).

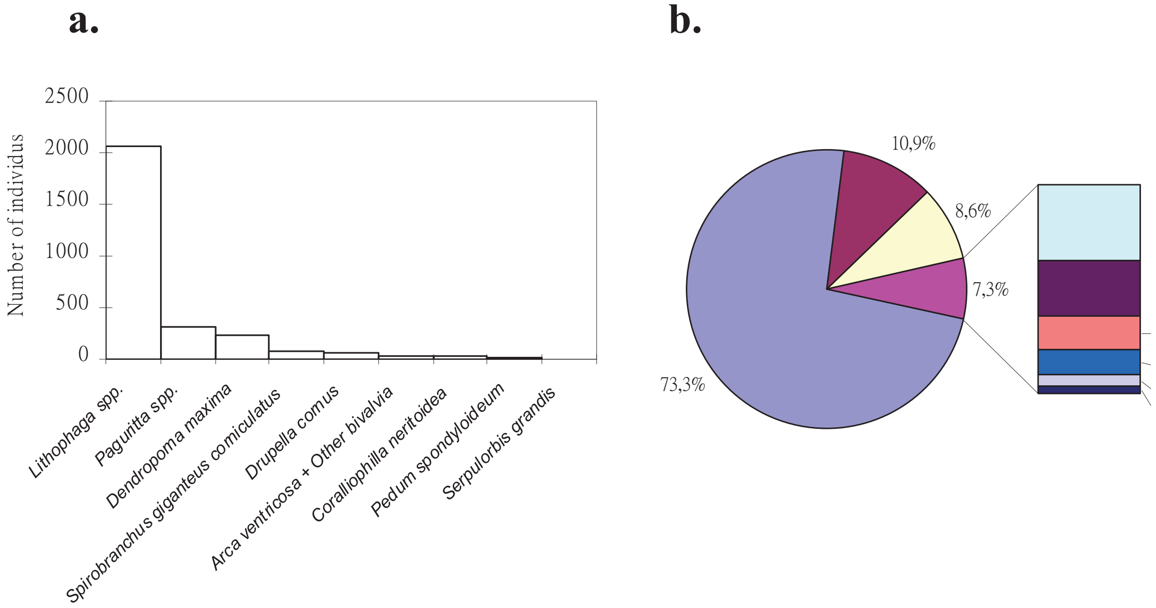


Figure 2. (a.) Number of coral associates recorded during this study ; (b.) Repartition of the different coral associates.

Table 3. Density of coral associates for the major form and genera of scleractinian corals infested (ind. m² of colony^{-1}).

	Coralliophila neritoidea	***Dendropoma maxima***	***Drupella cornus***	***Serpulorbis grandis***	***Arca ventricosa* + other bivalvia**	***Lithophaga spp.***	***Pedum spondyloideum***	***Spirobranchus giganteus corniculatus***	***Paguritta spp.***
Total massive colonies	0,22	0,85	0,06	0,13	0,53	8,73	0,22	0,28	0,66
Total encrusting colonies	0,12	5,00	0,14	0,07	0,19	40,48	0,09	1,27	6,22
Massive *Porites*	0,84	2,05	0,12	0,00	1,57	6,88	0,72	0,48	2,17
Encrusting *Pavona*	0,00	5,62	0,00	0,00	0,09	88,10	0,09	1,31	5,62
Encrusting *Montipora*	0,23	6,04	0,17	0,06	0,35	21,84	0,17	1,86	9,87

Infestation by Site

More than half of the coral colonies were infested in Pak Kasim's (54%) and Sampela (52%) (Table 4) whereas 44% of the coral colonies were infested in Buoy 3 and only 32% in Kaledupa.

The distributions of coral associates in the different studied sites are illustrated in Figure 4. All the coral associates were found in Pak Kasim's and Sampela whereas *Drupella cornus* and *Serpulorbis grandis* were absent in Buoy 3 and Sampela respectively (Fig. 4).

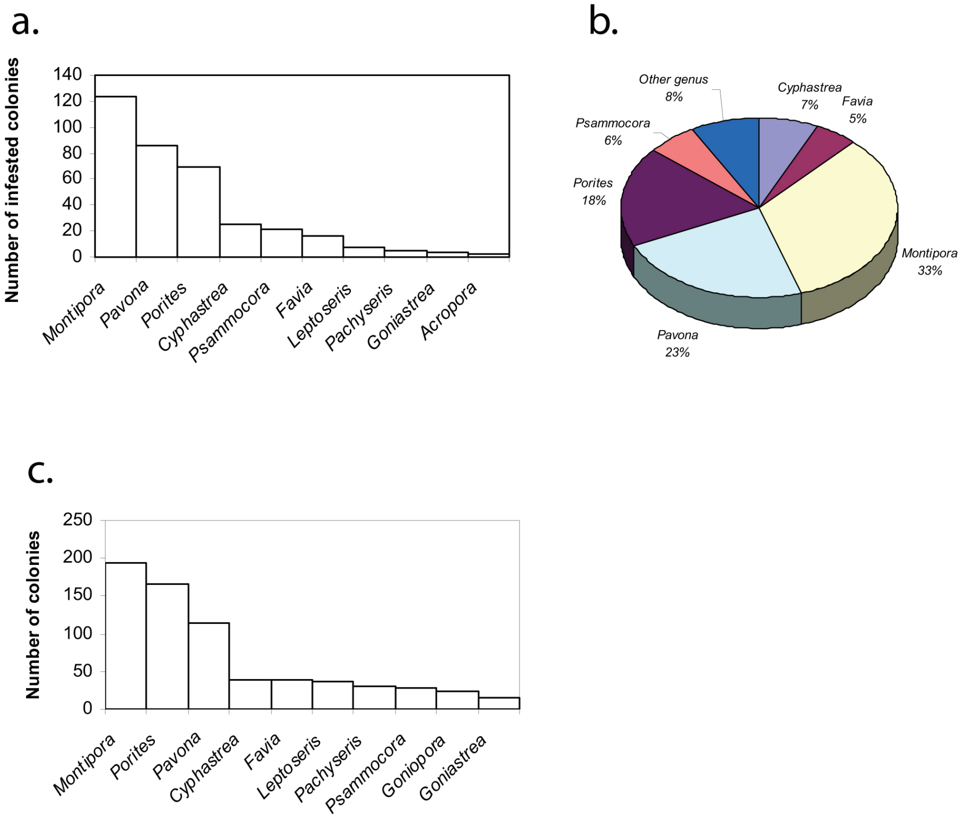


Figure 3. (a.) Number of scleractinian coral colonies infested for the ten most infested genera; (b.) Percentage of the number of colonies infested corresponding to a given genus on the total number of infested colonies; (c.) Number of colonies for the ten most common scleractinian coral genera.

Table 4. Total number of colonies recorded, infested, and percentage of infestation by site.

	Kaledupa	**Buoy 3**	**Sampela**	**Pak Kasim's**
Total of colonies	203	242	126	260
Total of infested colonies	64	106	65	141
% of infested colonies	32	44	52	54

Within the same site, no significant difference was found between the two chosen depths (6 and 12 meters) in terms of the total number of infested colonies and the distribution of the studied organisms. In consequence, no statistical significant difference (ANOVA One-way) for the parameter “depth” was found.

A highly significant difference between locations (ANOVA One-Way, F=18.42, p<0.01) was noticed only for the lithophagid bivalves. The distributions of coral associates in Sampela and Pak Kasim’s were significantly different from those in the other sites (Tukey’s pairwise comparisons). However, the difference between locations was significant for p-value < 0.1 for the gastropods *Coralliophila neritoidea* and *Drupella cornus* and for the dwelling hermit crabs of the genus Paguritta (Fig. 4). Composition of coral associates communities by site (a. Kaledupa b. Buoy 3 c. Sampela d. Pak Kasim's).

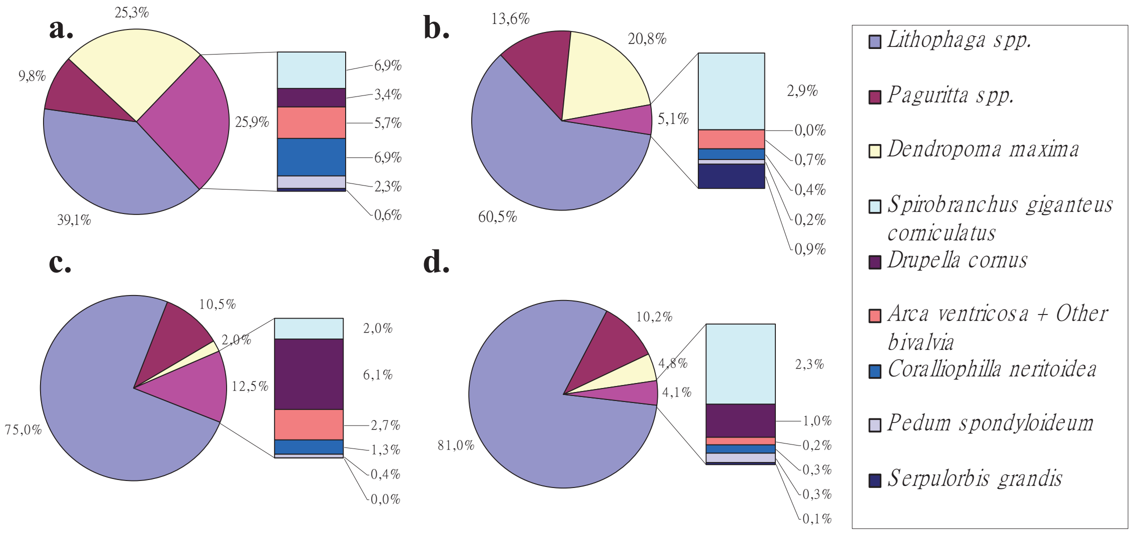


Figure 4. Composition of coral associates communities by site (a. Kaledupa b. Buoy 3 c. Sampela d. Pak Kasim's).

CommunityAnalysis.

Comparison of coral associates communities by Non-metric Multidimensional Scaling (MDS) and analysis of similarity (ANOSIM) indicated a significant difference among sites (ANOSIM One-way, Global R = 0.691, p=0.001) (Table 5). In contrast, no significant difference was found with regards to depth.

Table 5. Results of the ANOSIM tests comparing coral associates communities between the different sites.

	R Statistic	**Level (%)**
Global Test	0,691	0,1
Pairwise comparison sites		
Kaledupa / Sampela	1	0,3
Sampela / Buoy 3	1	1,2
Pak Kasim's / Kaledupa	0,994	0,1
Pak Kasim's / Buoy 3	0,846	0,2
Kaledupa / Buoy 3	0,274	2,6
Pak Kasim's / Sampela	0,191	16,7

Examination of the MDS plot (Fig. 5a) and cluster (Fig. 5b) showed a tendency of differentiation between the sites. Furthermore, pairwise comparisons of sites from ANOSIM resulted in R-values indicating important differences between Pak Kasim's / Kaledupa, Sampela / Kaledupa, Sampela / Buoy 3 (with R-values > 0.9) and between Pak Kasim's / Buoy 3 (R value >0.8). No difference was found between the other paired sites. However, with regards to their positions on the MDS plot, the stations seem to be positioned along a gradient between two sites: Kaledupa and Sampela. These results were confirmed after superposition of the Euclidian distance calculated and obtained from the cluster on the MDS. We observed two distincts groups of transects on the MDS and cluster, the first one inclucling transects from Sampela and Pak Kasim's and the second one including transects from Buoy 3 and Kaledupa.

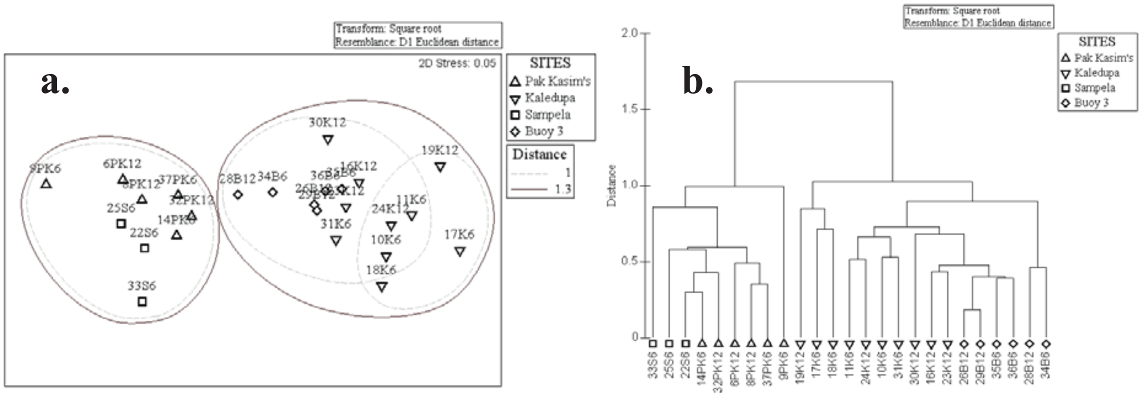


Figure 5. (a.) Multidimensionnal Scaling (MDS) on the analysis of bioreoder and coral predator communities (b.) Cluster based on the analysis of bioeroder and coral predator communities (codes displayed on the MDS and on the cluster represent the name of transects and their characteristics: transect reference – localisation PK: Pak Kasim's, K: Kaledupa, S: Sampela, B: Buoy 3 – depth of the transect (6 or 12 meters)).

The superposition of the densities of the lithophagid bivalves on the MDS (bubble plot shown in Figure 6) shows that the replicates of the sites with the highest Lithophagid densities (Sampela and Pak Kasim's) are separated by the greatest distance from those of the site considered as the most "pristine" (Kaledupa) in which the density of *Lithophaga* spp. is the lowest (all densities < 1 ind.colony^{-1}). Thus, the pattern observed when the densities of lithophagid bivalves are superposed on the MDS seems to be coherent to the trend of the potential gradient between Sampela and Kaledupa.

Link with Coral Reef Status.

Percentage covers of abiotic and biotic categories as well as soft and scleractinian corals in the four studied sites are represented in Figure 7. No significant difference in scleractinian cover was observed at the same site for different depths. In contrary, significant differences were noticed between sites for the same depth.

The biotic cover of Sampela was significantly lower than the other sites (Kruskall Wallis test, $p<0.01$). No significant difference concerning biotic cover was observed

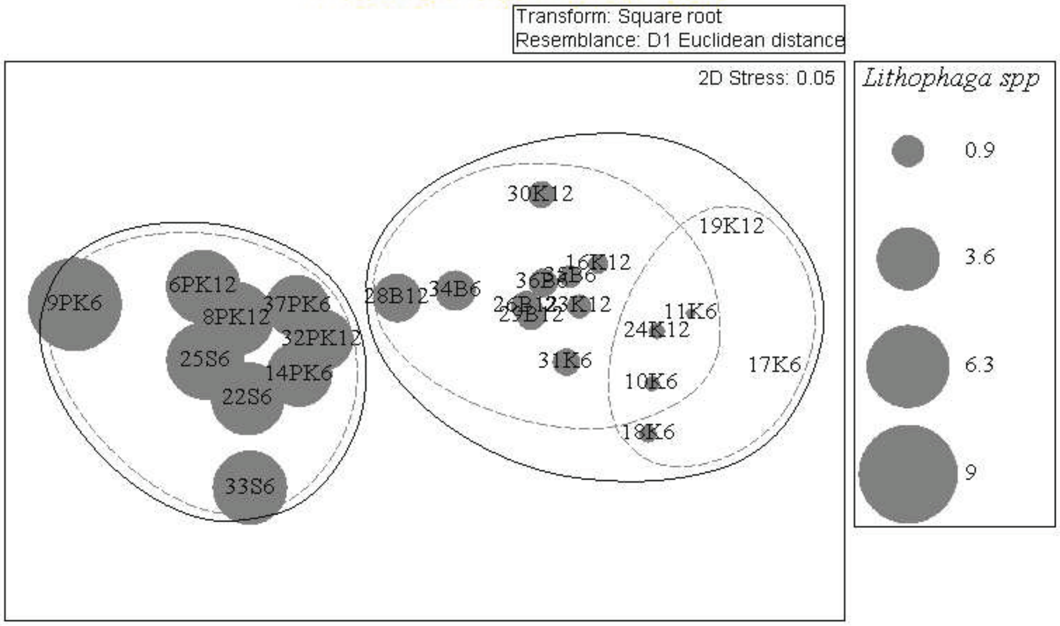


Figure 6. Bubble plot superposing the densities of *Lithophaga* spp. on the MDS (ind.coral colony^{-1}).

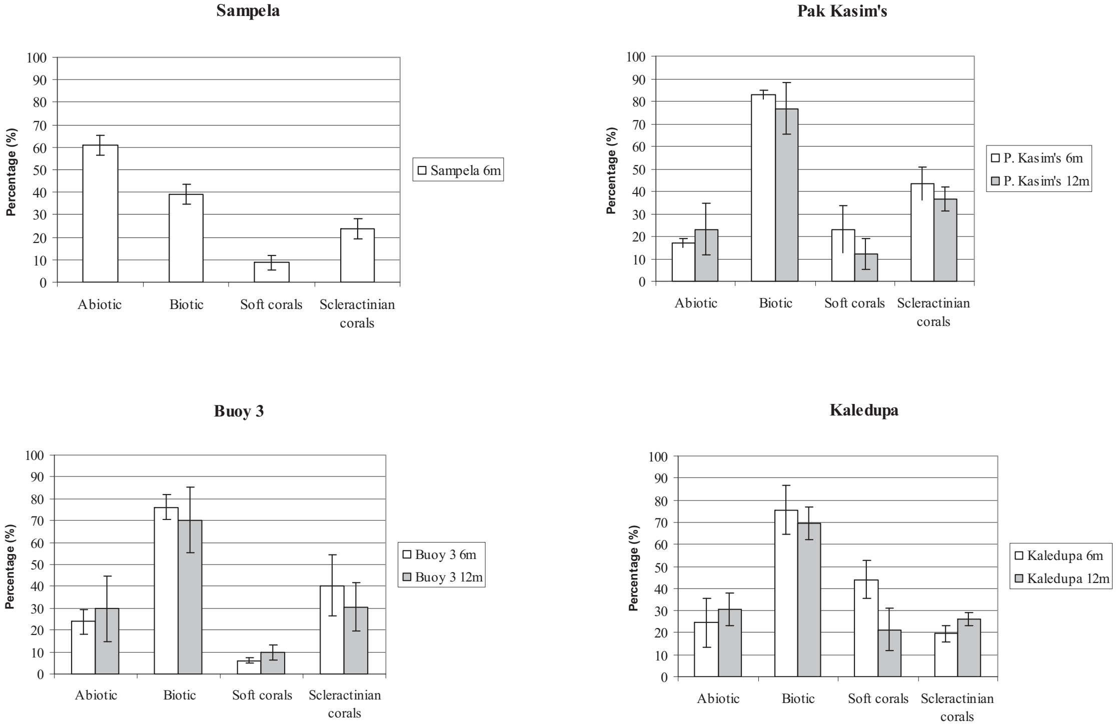


Figure 7. Summary of the benthic cover in the four studied sites (Sampela, Pak Kasim’s, Buoy 3 and Kaledupa).

between Pak Kasim's, Kaledupa and Buoy 3 whatever the depth of the transects. Soft coral cover was significantly higher in Kaledupa compared to the other sites and scleractinian cover at this site was consequently significantly less important than the other sites (Kruskall Wallis test, $p<0.01$).

Although the results of the LIT used in the survey method indicate that the number of colonies in Sampela (126 colonies for three transects (Table 4)) was in the same order of magnitude than in Buoy 3 and Pak Kasim's (respectively 242 and 260 colonies for six transects (Table 4)), the scleractinian cover in Sampela (23 %) was significantly less important than in the other two sites (40%). The difference observed can be attribuable to the occurence of small colonies in Sampela.

Kaledupa and Pak Kasim's had a higher proportion of branching corals (multiple non parametric Kruskall Wallis tests). Concerning the other categories of life forms (encrusting, massive and foliose corals) no statitical difference were observed between the sites.

DISCUSSION

This study indicates that mytilid bivalves of the genus *Lithophaga* were by far the most common live coral associates in the four studied sites. Other coral associates (boring bivalves: *Arca ventricosa*, *Barbatia foliata*, *Pedum spondyloideum*, *Modiolus philippinarum* and *Gastrochaena* spp., corallivorous gastropods: *Coralliophila nerioidea* and *Drupella cornus* and excavaters: vermetid gastropods *Dendropoma maxima* and *Serpulorbis grandis*, Christmas tree worms *Spirobranchus giganteus corniculatus* and hermit crabs of the genus *Paguritta*) were less common and contribute only little to total coral infestation. Previous studies about association of macroborers and live corals also indicate that *Lithophaga* spp. were the main bioeroder species in live corals. Scott et al. (1988) showed that infaunal associates of live scleractinian corals in the tropical eastern Pacific at Isla del Caňo, Costa Rica, consisted primarily of the living mussel *Lithophaga*. Similarly, Fonseca et al.(2006) demonstrated that the dominant non-colonial macro boring families in south Pacific coral reefs of Costa Rica were lithophagid bivalves with the bivalves considered the main internal bioeroders due to their greater body size and abundances.

Coral species on Hoga and Kaledupa islands are mostly encrusting (genera *Montipora* and *Pavona*) but some massive species (genus *Porites)* also occur. It is necessary to note that in this study the density of infestation by lithophagid bivalves (maximum 88 ind/m^2 in encrusting corals of the genus *Pavona*) are less important than those reported in the East Pacific where *Lithophaga* reaches unusually high abundance (up to 100 ind/0.01 m^2) (Scott and Risk, 1988). On the contrary to the tropical eastern Pacific massive species of the genus *Porites* are not heavily infested by lithophagid bivalves. In our study sites approximately 45% of the massive *Porites* species are infested by *Lithophaga* spp. and the density of infestation is only 6,88 ind/m^2. In the tropical eastern Pacific, most commonly inhabited was the main reef builder *Porites lobata.* Approximately 90% of the colonies contain lithophagid bivalves, with mean densities ranging from 480/m² of coral surface in Galapagos to 3060 and 1870 ind/m² in Panama and Costa Rica, respectively. The only coral genus never attacked by *Lithophaga* was *Pocillopora*. In contrast, Cantera et al. (2003) reported that off the Pacific coast of Columbia (Gorgona Island) boring bivalves of the genus *Lithophaga* are the most important group of macroborers of the branched coral *Pocillopora damicornis*. Live massive colonies of *Porites lobata* on the barrier reef of Tiahura, Moorea, French Polynesia contain only three species of coral asociates, the bivalve *Lithophaga laevigata*, the vermetid *Dendropoma maxima* and the serpulid *Spirobranchus giganteus* (Peyrot-Clausade et al., 1992).

Based upon sedimentation rate, rugosity, light attenuation coefficient and low biotic cover, Sampela can be considered as an impacted site. In contrast, the sedimentation rate at Kaledupa is slighthy lower and reef complexity is higher than at the other sites. In a previous study, Crabbe and Smith (2002) found a significantly higher hard coral species richness at Kaledupa than at Sampela. This agrees with the observations of Edinger et al. (1998) who demonstrated that in Indonesia (Ambon, Spermonde Archipelago and Central Java) reefs subject to land-based pollution (sewage, sedimentation) show 30-50% reduced diversity at 3 m and 40- 60% reduced diversity at 10 m depth relative to unpolluted comparison reefs. Moreover, the survey of keystone organisms contributing to reef degradation revealed a high number of sea urchins in Sampela. An average of five individuals of *Diadema* spp. per transect (50 m-long transect) was observed in Sampela in comparision with a maximum of one individual per transect for the other sites. Although, the number of urchins by transect was relatively low, the difference was statistically significant. Concerning *Acanthaster planci*, no relevant number of this organism was recorded. A maximum average of 1.6 individuals per transect (50 m-long transect) was recorded at Kaledupa but no significant difference was found between the sites. Data on earlier densities of these “keystone species” would be very useful in explaining the state of the actual populations. Furthermore, visual observations of holes created by bioeroders on dead corals at Sampela led to conclude that bioeroder activities, especially those of boring lithophagid bivalves, play a fundamental role in the degradation of this site. Due to the proximity of the Bajo village near Sampela high nutrient and organic matter concentrations could reduce biotic cover and coral diversity, favor invasion by opportunistic organisms like macroborers and increase the destruction rate (Pastorok and Bilyard, 1985).

Coral associates’ diversity was not affected by the degree of degradation of the reefs; however, the densities of lithophagid bivalves were higher in Sampela and Pak Kasim’s. Analysis of coral associates’ communities showed that despite the lack of any significant difference in biotic cover between the three sites Kaledupa, Buoy 3 and Pak Kasim’s, a common gradient tends to emerge. The superposition of bioeroders’ densities on the MDS plot showed the essential role played by the boring lithophagid bivalves, which probably contributes to the similarity between Sampela and Pak Kasim’s. Although the biotic and coral cover of Pak Kasim’s are high, this site also suffers from a similar level of infestation and perturbation as Sampela. However, unlike Sampela, visual observations and monitoring methods at Pak Kasim’s did not reveal a substantial number of dead corals infested by bioeroders as in Sampela. It suggests that this site is going through the process of reef degradation previously experienced at Sampela (Fig. 8).

The survey of live scleractinian corals associates and specially of macroboring lithophagid bivalves could also be used to assess the health of coral reef during coral reef long-term monitoring in particular for reefs in the course of degradation and who can not be evaluated by traditional indicators of coral reef status (coral cover). In conclusion, as proposed by Risk et al. (2001), coral associate counts can be a simple technique to identify stress on reefs.

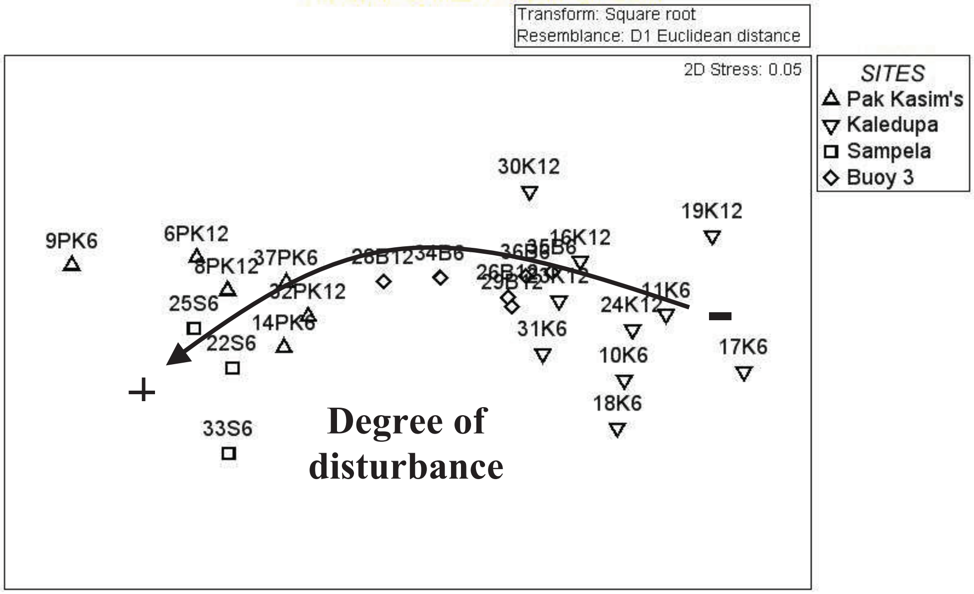


Figure 8. Position of the sites' replicates on the MDS superposing a degree of disturbance existing between the sites (codes displayed on the MDS represent the name of transects and their characteristics: transect reference – localisation PK: Pak Kasim's, K: Kaledupa, S: Sampela, B: Buoy 3 – depth of the transect (6 or 12 meters)).

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