~UR 128 CoRéUs~

Preliminary *in situ* and remote sensing assessment of habitat diversity and coral cover along Abore Reef (New-Caledonia)

Photo by Catherine Geoffrey

Annick Cros [1]
cros@noumea.ird.nc

Under supervision by Serge Andrefouët

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IRD Nouméa, UR CoRéUs, New Caledonia

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1. Introduction

The Abore reef is a 25 km long barrier reef, situated approximatively 20 km east of Noumea, New Caledonia. Due to its marine reserve status and its proximity to New Caledonia's largest town, it has been relatively well documented over the past 20 years with several fish-oriented surveys (Amand et al. 2004, Kulbiki et al. 1996, Sarramegna 2000, Pelletier et al. 2004). However, the data remains spatially limited in time and space and previous information collected to describe the substrate is limited to few tens of transects issued from fish survey protocols.

Our interest here is to document the variety of habitats present along the Abore barrier reef (outer slope excluded), with a special focus on the state of the coral cover. Coral cover is only one of the variable that is included in a habitat description, but it is highly important because it is a central component of coral reef ecosystems and a source of food and habitat for many species including commercially important species (Lesser, 2004). Correlations have been demonstrated between architectural complexity of the substratum and fish population (Luckhurst and Luckhurst 1978, Sano et al. 1984, Roberts and Ormond 1987, Chabanet et al. 1997).

Abore reef has been hit by hurricane Erika in 2003 and a change in the architecture of habitats and coral cover may have influenced the status of fish communities. Therefore, the long-term goal of this research is to review at a synoptic scale the habitat and coral cover history of this reef in order to assess the relative influence of management practices and natural perturbations in the current status of fish community.

This is a complex problem. To address it, we need to break up the study in several stages using different data sets:

- High resolution remote sensing data is required to satisfy the synoptic scale of the habitat and coral cover assessment. Remote sensing technology is increasingly used for the management of coral reef resources. Due to its synoptic scale, availability of few meter resolution multispectral images and relatively low cost (Green et al. 2000), it allows the mapping of the reef habitat with excellent accuracy.
- However the direct estimation of coral cover using optical remote sensing data is not demonstrated so far. Thus, we need to evaluate its feasibility for Abore Reef.
- For this, we need to collect input data from the field for both habitat mapping and coral cover mapping. Thus, we need to elaborate the required field protocol that will feed the mapping process.
- Once the methods are validated, the final stage is to compare time-series of images in terms of habitat changes and coral cover changes. The validation of this analysis needs modern data, that we have collected, but also historical coral cover data that poses new challenges.

Beyond just the Abore Reef case study, methods developed here are potentially useful in other sites along the New Caledonia barrier reef, to monitor changes due to natural disasters or man-induced disturbances such as fishing, sedimentation or pollution. It can also be the appropriate tool to decide where to establish marine protected areas in function of reef habitats diversity.

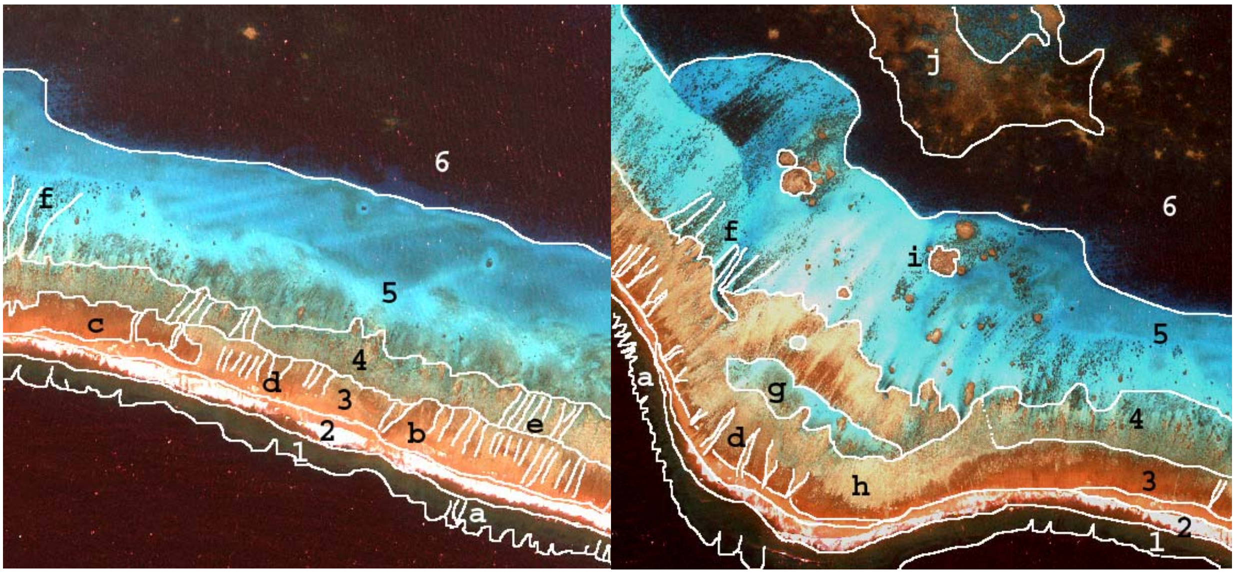
Specifically, this project will use three satellite sensors, 1/ a high resolution IKONOS satellite image of the Abore Reef acquired in 2002, 2/ a Landsat 7 ETM+ image acquired in 2001, and 3/ a Quickbird image collected in 2004.

2. Methods

2.1. Site description

The Abore reef is a 25 km long barrier reef, situated approximatively 20 kilometers east of Noumea. It is delimited by two passes, the Boulari pass at the south tip (lat: 22°29'43.35"S, long: 166°26'34.76"E), and the Dumbea pass at the north tip (lat: 22°21'19.76"S, long: 166°15'23.62"E). A shipwreck "Ever Prosperity" (lat: 22°27'21.10"S, long: 166°22'0.24"E) roughly divides the reef in two regions, "North Abore" and "South Abore".

The geomorpholy of Abore reef can vary along the reef itself. Two examples are given in Fig 1 and 2. We recognize the usual structure of a barrier reef with an outer slope, a reef crest, a reef flat, the back reef, inner slope and lagoon. A look at a finer scale reveals differences that may indicate differences in habitats and live coral cover.



1. Outer slope/Pente externe
2. Reef crest /Crête récifale: impact zone/ zone d'impact
3. Reef flat/ Platier interne
4. Reef patch/Platier diffus

Large boulders and large structure of dead or live massive coral which are not connected.

5. Sandy accumulation and inner slope/Accumulation sédimentaire et pente interne
6. Lagoon

a. Spur and grooves/Eperons et sillons
b. Shingle spread on pavement /Epandage détritique sur dalle
c. Compact reef/ récif compact
d. Transverse stripes/ alignements transversaux
   -darker colour: usually live coral but here it is dead coral encrusted and rubble covered by turf.
   -lighter colour: usually sand, and rubble on pavement
e. Sand channel separating large structures of dead or live massive coral
f. Shingle spread/ épandage détritique
i. Isolated reef patch/ patates isolées
j. Reticulated reef/ récif réticulé
g. Inner reef pool/ Retenue d'eau de platier interne
h. Compact reef/platier compact

Fig. 1 Geomorphologic zones of two areas on South Abore, legend and description. Terminology from Battistini et al. (1975)

The reef flat is situated at a depth of about 1m, with a tidal range on the reef which varies between 0.1 and 1.65 m. The deeper part in the lagoon (locally called “Forest” due to high density of branching corals) lies above 10m depth. Thus, most of Abore Reef structure falls in the limit of visibility of the remote sensing image.

2.2. Survey’s general characteristics

The purpose of the field work is two-folds:
- acquire training data that will be used to make the habitat maps and collect coral cover information
- acquire independent validation data to assess the accuracy of the maps and the estimates of coral cover

The IRD R/V CORIS was used for transportation to the reef. However it could not approach shallow sites such as the reef crest. One underwater scooter was shared between 2 divers, to cover all sites on the reef flat and on large isolated reef patches. SCUBA diving gear was only used for sites deeper than 1.5m. The rest of the sites were surveyed with snorkelling gear.

For both surveys and ground truthing, a hand held ground positioning system (GPS) in a PVC waterproof casing was used to mark precisely position of data collection.

In the course of the project (4 months), five different observers were trained and carried out all field work.

Site selection

- Training sites

Originally, the study was to be carried out on the entire Abore reef. However, due to delays in tasking new imagery, , the only available high resolution image was an IKONOS image, (Table 1). It covered the southern half of the reef from the Ever Prosperity Shipwreck to the Boulari pass. Therefore most of the field data collected is located on South Abore although four days of sampling based on the Landsat 7 image (Table 1) were spent on North Abore for future data use.

Unfortunately, we received the Quickbird images (Table 1.) covering the entire reef only the last two weeks preceding the end of this preliminary study. They will be used hereafter only in the discussion to show the potential in terms of time-series analysis.

Satellite	Acquisition date	Spatial resolution
Ikonos	16-avr-2002	4×4 m
Landsat ETM+	21-fev-2001	30×30 m
Quickbird	20-dec-2004	2.5×2.5 m

Table 1. Characteristics of the IKONOS, Landsat ETM+ and Quickbird images.

The reef was divided by geomorphologic zones: reef flat, inner slope, lagoon, isolated coral patches.

For training, we surveyed individual point-sites selected on the satellite image on the basis of colour and texture in order to capture the variety of signatures in the images, under the hypothesis that each signature will point to different habitats and coral cover.

- Control sites

Accuracy assessment data were collected on the same geomorphologic zones as training sites, but were surveyed along the tracks of long transects criss-crossing the reef.

Habitat description

The first step to this project was to establish a sampling protocol for habitat description. The choice of the approach was influenced by existing habitat descriptions methods used previously elsewhere in Mayotte, French Polynesia and the Caribbean for remote sensing studies and by both IRD and SPC for fish assessment. Therefore we used a modified version of the SPC/IRD habitat forms which included architecture information also collected for high resolution habitat mapping (Annex 1). In short, categories were semi-quantitavely recorded using a three level hierarchy: 1/ percent cover of *Hard* and *Soft Bottom*, 2/ detailed percent cover of these two fractions, i.e. rubble and sand for *Soft Bottom,* and coral, dead coral, rock, etc for *Hard-Bottom*, 3/ descriptions of coral growth forms and details of algal types.

Habitat were described along 30 or 50-meter transects, with one observation every five meters, integrating 2.5 meters on each side of the transect, thus one habitat description covered ~25 m² and one transect covers 150 to 250 m².

Most habitat data were recorded as a semi-quantitative index. In order to average the data along the transect, semi-quantitative data were transformed as a percentage using the fish surveys protocol (Kulbiki, pers. comm., see Annex 3 for method).

Coral cover

Standard line intercept transects (LIT) and habitat descriptions were done simultaneously to find quantitative measurements of the same variables between LIT and habitat sheets. Both methods were carried out on the same transect by the same observer. Since LIT provides a percent cover of a range of variables, the data can also be used to define habitats, but without including some specific reefscape variables (such as topography etc…).

2.3. Comparing LIT and Habitat forms

For LIT data, the sum of the length of each category measured along each LIT was transformed into % cover over the 30 or 50m transect.

For Habitat data, the index of each category was transformed into the corresponding % cover. These % cover were then averaged over the 30 or 50m transect and transformed into the percentage of the average % cover of all categories (Kulbiki pers.com, Annex 3).

LIT and Habitats provided respectively measurement and estimates of percent cover for a range of variables, at two different scales. However, since they were done in parallel on the same transects some correlations are expected and should be found (Long et al. 2004). It is interesting to evaluate this correlation since Habitat forms are largely subjective and based on the observer experience, while LIT data are more objective. A poor correlation will likely point to estimation problems when filling the Habitat sheets. Conversely, the comparison between the LIT and Habitat methods may validate the Habitat form as a relatively fast method to estimate live coral cover within a reefscape.

Two analyses were carried out to compare the two coral cover variables:

1. Regression analysis, Habitat against LIT
2. Paired sample T-test

2.4. Definition of habitat classes

A hierarchical cluster analysis was carried out on both LIT and Habitat data using PRIMER and results were plotted as dendograms (Legendre and Legendre, 1998) to help define the habitat clusters. A Simper post classification analysis was used to identify the variables that were dominant for each cluster.

2.5. Supervised image classification

The mapping of the habitats present on Abore Reef was performed using a supervised classification algorithm. The Maximum Likelihood algorithm was selected since it generally provides the best results for well defined statistics (i.e. with enough training points).
Three classifications were done separately and then merged, to avoid misclassifications between different zones with different habitats. We classified separately 1/ the reef flat, 2/ the inner slope, 3/ the lagoon. Five, four and six habitats were present on each zone respectively. It has been shown on several sites, e.g. Lee Stocking Island, Bahamas, (Tyler 2003), and Mayotte barrier reefs, (Andréfouët et al. 2003), that this pre-segmentation by geomorphologic zone increases the accuracy and thematic richness of the maps, compared to one-pass processing.

Accuracy of the classification was quantified using confusion matrices (User and Producer accuracy) computed with ENVI® software. Overall accuracy and Kappa (K) provide two measures of accuracy across all the classes, thus without details of individual class accuracy. K expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification (Green et al., 2000).

3. <u>Results/ Discussion</u>

3.1. Comparison of survey methods

A total of 95 training sites were surveyed using LIT, of which 53 were used for analysis (Fig. 2). 124 training sites were surveyed using the Habitat forms, of which 85 were used for analysis (Fig. 2).

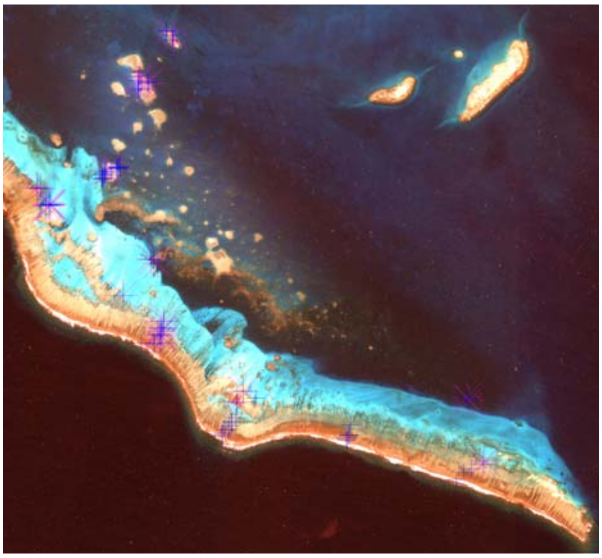


Fig. 2 Location of LIT (magenta) and Habitat (blue) transects on South Abore.

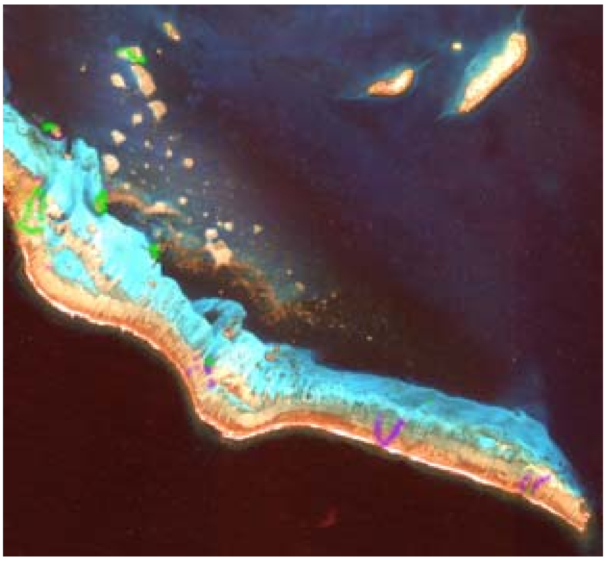


Fig. 3 Location of control sites including observations (purple) and 5*5m quantitative data (green).

There were 48 sites that were surveyed both through LIT and Habitat forms. 200 additional points were collected either as qualitative observations or 5*5m quantitative descriptions, for validation and accuracy assessment of the habitat map and coral cover estimates (Fig. 3).

The comparison between the percentage live coral cover measured by LIT and Habitat form for each site is presented in figure 4. They coincide overall, though generally Habitat underestimates *Live Coral* cover compared to LIT.

The sites range from the earliest date (25/10/04) to the latest (27/01/05). The difference between LIT and Habitat seems to decreases in time. This would indicate that part of the difference observed may be due to the length of time of the observer's training and that the estimation of *Live Coral* improves with time spent underwater.

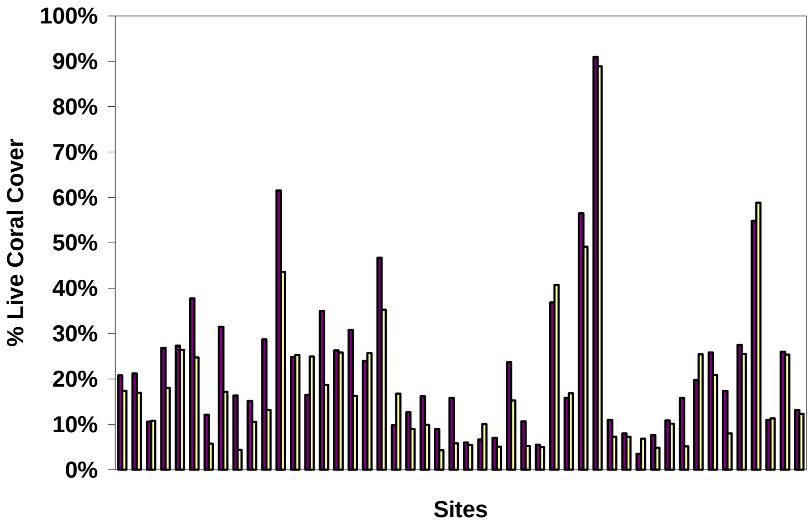


Fig. 4 % *Live Coral* cover for each site in common for LIT (purple) and Habitat (yellow). Sites are set in chronological order starting from the 25/10/04 to the 27/01/05.

Based on the raw data, a first paired sample t-test showed that there was a significant difference between the means of Habitat and LIT. The regression analysis highlights a positive offset (b= 0.0457, or 4.5% in terms of coral cover) in the linear relationship, explaining the Habitat tendency to underestimate *Live Coral* cover. This offset was systematically subtracted to the LIT data and the sample T-test was carried out again. This time the null hypothesis could not be rejected (Table 2, t=0.6 <critical value 2), with no significant difference between means for Habitat and LIT data. The regression analysis provides a positive correlation (R^2=0.859) between Habitat and LIT data (Fig. 5).

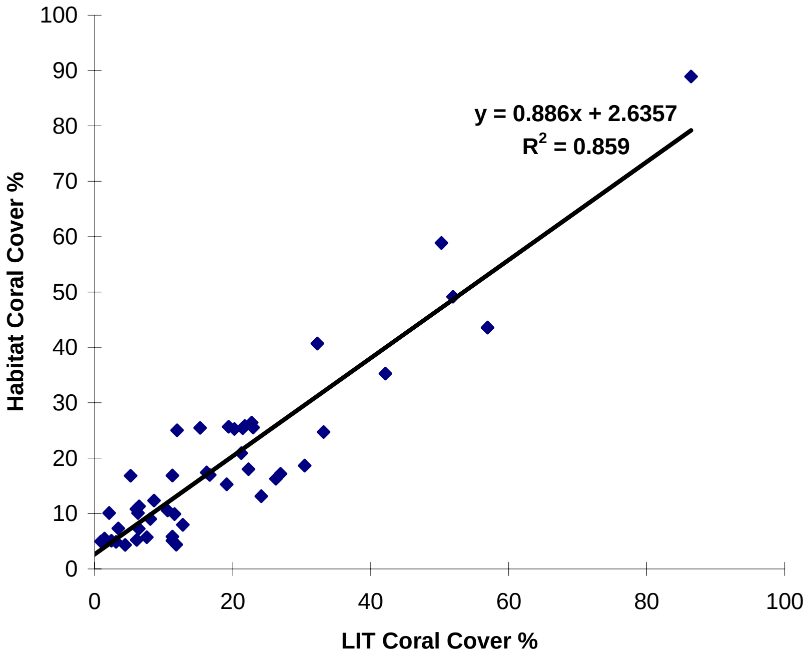


Fig. 5 Regression of Habitat against LIT Live Coral Cover, R^2 correlation coefficient and equation.

Table 2. Paired t-Test comparing Habitat and LIT average Live Coral Cover. $p<0.05$

LIT mean (± stdev)	Habitat mean (± stdev)	df	t	Sig. (2-tailed)
0.187 ± 0.026	0.181 ± 0.028	46	0.618	0.539

We believe the main reason explaining the discrepancy between the two data sets is the following. The observers have a tendency when filling out a Habitat form to systematically indicate the "presence" (so less than 1% in terms of cover) of a given variable by using a coded value of "1" (meaning from 1% to 10%). The transformation we applied when averaging coded values gives a percent cover of 5.5% to these "1" categories, thus it overestimate the % cover and in turn underestimate other variables (since all percentages or indexes are calculated to sum up to 100%).

Another possible reason explaining the discrepancy between LIT and Habitat *Live Coral* covers come from transect lines positioned with a bias towards higher coral cover. For this project, transects are often set within areas with high live coral cover in order to capture end-members in terms of coral cover. On the other hand, Habitat quadrats estimated over 25 m² are more likely to capture areas less dominated by corals and mixed with other habitat variables. Thus, a significant difference between *Live Coral* cover may just reflect different spatial heterogeneity, which is aggravated when averaging transects value along 30m of LIT data and 150 m² of Habitat data.

However, the 4% difference between Habitat and LIT data is inferior to the "original" variation inside the interval defining the index categories. This difference therefore remains small and acceptable, validating the use of the Habitat form instead of the LIT method which generally is more time-consuming than the Habitat method. Nevertheless, this comparison sets the limits of use of Habitat descriptors to monitor changes in habitat structures focussing on live coral cover variations. Finally, we suggest that there is scope for improving the transformation of index into percentages and by adding one code to reflect the “presence” of a variable.

Long et al. (2004) carried out research on the accuracy of a new technique called the reef resource inventory (RRI) where they estimated the percentage cover of categories of benthos and substratum along 2 × plotless strips-transects. They compared this technique based on observer estimation against LIT technique by repeating both methods of survey on the same transects. They carried out a regression analysis of RRI against LIT (n=51) and found a correlation coefficient of 0.938. This is a very similar result to ours (R^2=0,859, n=48). They estimated the time to sample a 20m RRI to 5 minutes. Thirty meter Habitat forms take about 10 minutes if we record the same amount of information as is recorded by RRI. These two methods are therefore comparable to record objective, but faster, estimation of *Live Coral* cover.

3.2. Evolution of Habitat forms

The comparison between LIT and Habitat forms provides a good match. However, it uses a sub-sample of 48 joint measurements, after a significant number of data collected were discarded because of their quality and consistency.

We discuss here the problems encountered during this study:

First, the main change made to the original IRD/SPC habitat form was to include more detail about coral cover by adding additional growth forms and colony sizes for both live and dead coral. This allowed to get a better "photographic" idea of habitats just by looking at the forms, but also added significant complexity and significant time to collect the observations during the first surveys. Eventually, with practice, time decreased and consistency increased for all observers, but it is a fairly long process to calibrate the observers. The rules to fill the form were presented the first time but not understood in the same way. In particular, we noted:

1/ Miss-classification of coral forms and colonised substrate.

- Difference between branching, digitate and tabulate forms were loosely perceived. Some intermediate forms such as columnar and sub-massive were described either as *Digitate* or *Branching*. Young colonies were also a source of disagreement between divers.
- There was some confusion with eroded rocky substrate which was either described as *Rock* or as *Pavement*.
- *Soft Substrate* and *Hard Substrate* were not clearly delimited because of the presence of boulder categories and there were no good quantitative references to discriminate *Small* and *Large boulder*.

  As a consequence, it was necessary to regroup variables to eliminate several mistakes prior data analysis. Specifically:
- *Rock* and *Dead Coral Encrusted* were merged.
- *Rubble* and *Small Boulder* were merged.
- *Branching, Tabulate* and *Digitate* were merged, as well as *Massive* and *Encrusting*.

  This merging process resulted in the simplification and loss of details in habitat characteristics.

2/ Lack of suitable categories for what is observed in the field.

This is the case for intermediary forms of *Live Coral* such as columnar forms, sub-massive forms and fire-corals *Millepora* species.

As a consequence, observers did not record the coral forms under the same category and it was necessary to merge variables to eliminate several mistakes prior to data analysis. For example, columnar and sub-massive forms were considered as *Branching*. Data such as % cover of *Millepora* had to be discarded since it was inconsistently recorded.

This resulted again in the loss of detail and information in the data. We either had to return to coarser categories or we had to discard the data. Coral growth forms could potentially discriminate habitats variations and history, therefore regrouping, for example, columnar and branching corals could result in failure to identify a particular habitat.

3/ Confusion in the % cover.

Some covers were measured relative to the entire 5×5m² area, others provide details only relatively to a given category (ex: the sum of the different coral forms is 100%, even if there is 5% total coral cover). This resulted in confusion among surveyors, and some of the data had to be discarded.

4/ Lack of a "presence" index.

Categories which were present but without any significant cover (<1%) were still given a "1" to mark their presence. Due to the present method of going from index to percentage (see Methods), this overestimates the % cover and in turn underestimates other variables.

All these errors were minimized after a long period of training and calibrating of observers, but nearly half of the habitat data collected needed to be discarded. It is therefore essential that habitat forms are well explained before hand, in particular insisting on different categories and hierarchy of measurements. Time must also be spent in the water comparing notes on:

1-perception of % cover
2-live coral forms
3-substrate categories

We suggest that at least three full days of training, with several breaks for discussions throughout, are a minimum.

As a result of this work, we also suggest an improved version of the Habitat form (Annex 2) which was used by ZONECO habitat surveys in Lifou and Moindou in April 2004:

- *Rocky Substrate* floor category is added. It is rock with a frequent topography of 1 and complexity of 1.
- *Sub-massive* coral category is added. It has a wide morphological range and includes any branching form which does not fit into the strict *Branching* category or *Digitate* category. For example the form columnar fits under *Sub-massive*.
- *Crustose coralline* and *Encrusting Macro Algae* are merged because they are difficult to differentiate in the field at depth when surveying in snorkelling
- *Soft Substrate* and *Hard Substrate* are hierarchically divided into "sub-categories". These "sub-categories" (such as *Sand*, *Mud* and *Small Rubble* for *Soft Substrate*) are recorded so that the sum is equal to 100%.

- The index quotation is still kept for the revised version of the Habitat form. Observers were more intuitive when it came to quickly estimating covers than using percentages. The other advantage of this method is that it is faster to learn and to calibrate between observers. The variation in the index allows for a degree of uncertainty which is inherent when estimating a cover in an open space. However, several observers still prefer using percentage values which offer a continuous gradient of values.

3.3. LIT and Habitat cluster analysis

Habitat classes defined using LIT data

Using the dendrogram as a guide (Fig. 6), 8 classes of habitats were defined at a similarity threshold of about 70% (Fig. 7).

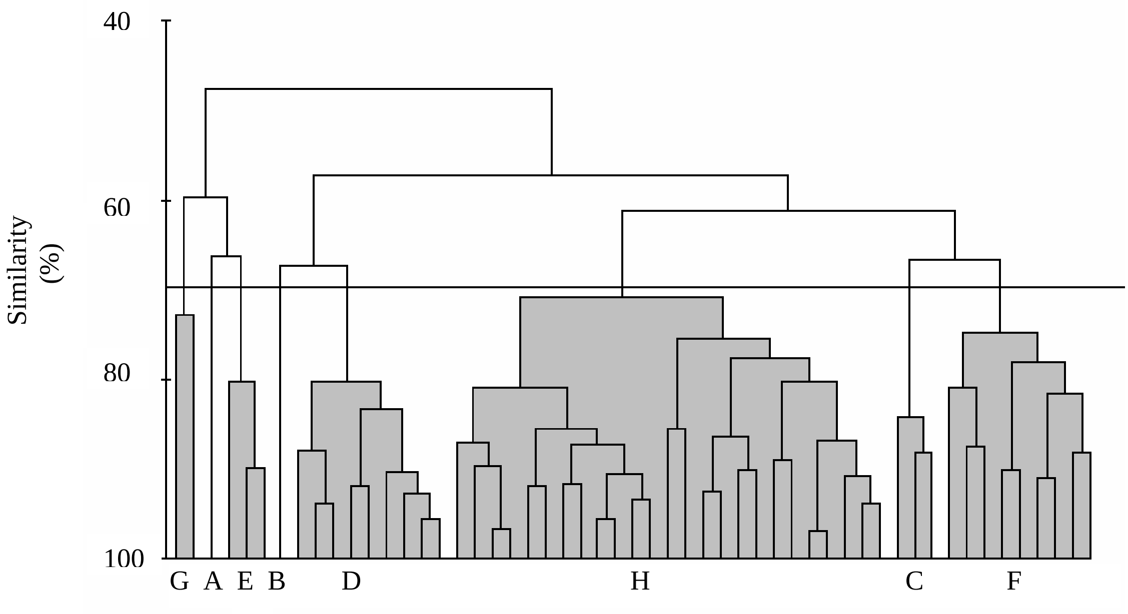


Fig 6. Hierarchical clustering of 53 "LIT" Abore training sites. 8 classes can be defined at a similarity threshold of 70%.

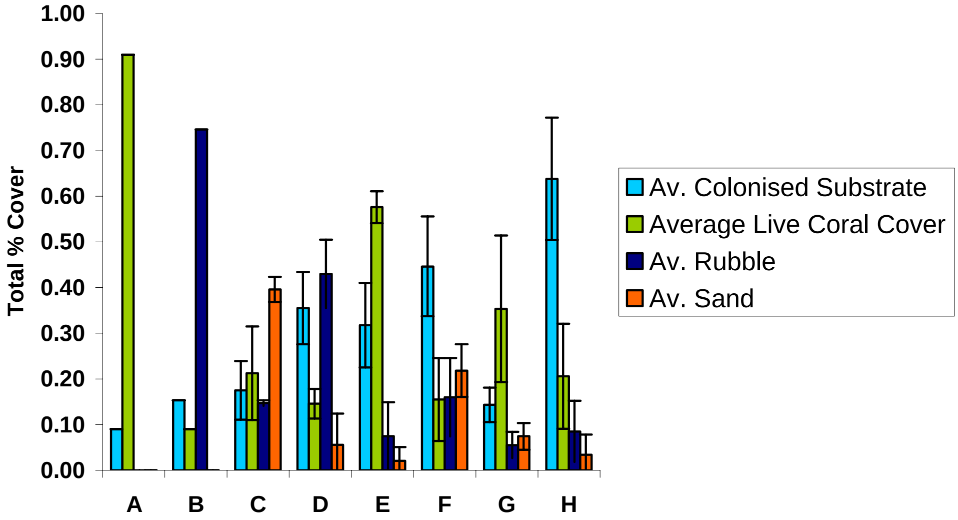


Fig. 7 Characteristics of habitat classes defined using LIT data, clustering and 70% similarity threshold: Average, standard deviation of classes for the four main discriminating variables identified by SIMPER. The absence of an error bar indicates classes with less than three sites.

Using a Simper analysis and our knowledge of the reef structure, these 8 original classes were merged into 6 final habitat classes. The data from each site in the new classes were used to compute a mean and a standard deviation of each class and match index categories. This way the classification could be applied directly in the field.

Table 3. Final classification scheme of Abore Reef using LIT based descriptors. LC: *Live Coral* (all forms mixed), CS: *Colonised Substrate* (*Dead Coral*, *Rock*, *Large Boulder*), SRU: *Rubble* and *Small Boulder*, SSA: *Sand*. *see annex 4 for list of sites found in each category and Annex 5.

Class LIT	Dominant type of bottom	Assigned % cover (index) LC	CS	SRU	SSA	Most likely to be found*
A	Exceptionally high live coral cover	>75% (5)	<10% (0-1)	Very little soft substrate <5%		Exceptional patches of reefs
B	Rubble	<10% (1)	1-20% (1)	>75% (5)	<5%	Towards the reef crest and isolated reef patches (rubble dome)
C	Dominated by sand, with live coral cover	11-30% (2)	11-30% (2)	15% (2)	31-50% (3)	Typically deep sites in the lagoon or inner slope
D	Dominated by rubble and colonised substrate with live coral cover	11-20% (2)	31-50% (3)	31-75% (3-4)	1-10% (1)	Mixed group with different location, but would be typical example of transition between reef crest and reef flat, and of the south tip of Abore reef.
E+G	Dominated by live coral cover, on colonised substrate	31-75% (3-4)	11-40% (2-3)	1-10% (1)	1-10% (1)	Reef flat, isolated coral patch, with high live cover. Typically presence of rocky substrate, near Ever Prosperity.
F+H	Dominated by colonised substrate, with live coral cover	1-30% (1-2)	31-100% (3-5)	1-30% (1-2)	1-30% (1-2)	Reef flat, isolated coral patch, with low to medium coral cover.

Habitat classes defined using the Habitat form data

Using the dendrogram as a guide (Fig. 8), 9 classes were defined at a similarity threshold of 50% because a higher threshold gave too many small (one site or two sites) classes (Fig. 9).

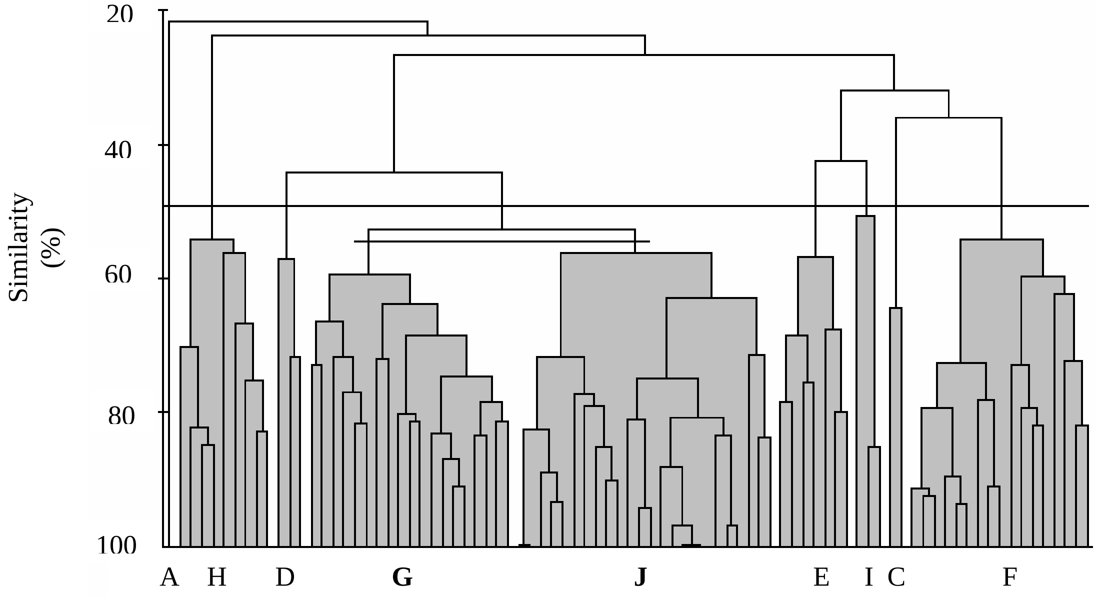


Fig. 8 Hierarchical clustering of 85 "Habitat" Abore training sites. 8 classes can be defined at a similarity threshold of 50%. Classes defined at 54% threshold are in bold.

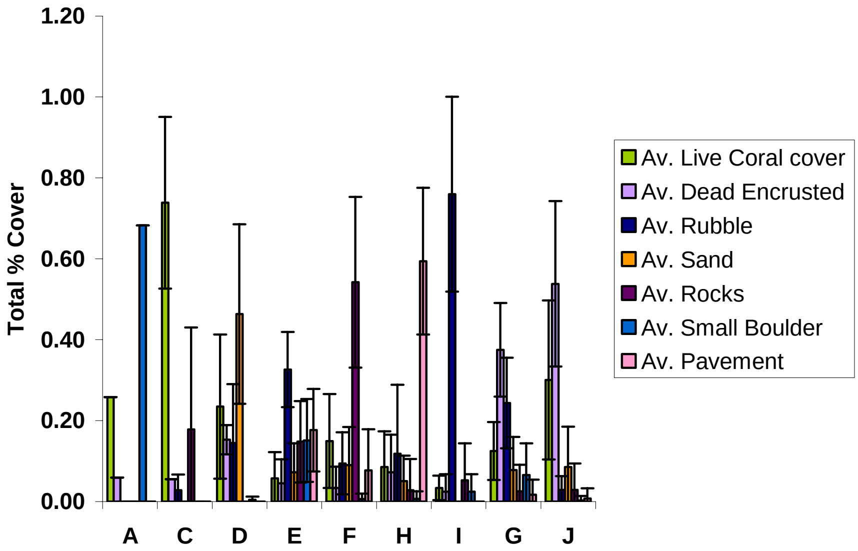


Fig. 9 Characteristics of habitat classes defined using Habitat data, clustering and 50% and 54% (J and G) similarity threshold: Average, standard deviation of classes for the four main discriminating variables identified by SIMPER. The absence of an error bar indicates classes with less than three sites.

Using a Simper analysis and our knowledge of the reef structure, we decided to split one of the classes into two (G and J, similarity threshold of 54%) and merge them again into 8 classes.

Intervals of percent cover for categories were assigned by taking into account the value of the average and standard deviation and to match index categories. This way the classification could be applied directly in the field.

Table 4. Final classification scheme of Abore Reef using Habitat based descriptors. In bold the two classes defined at 54% threshold. LC: *Live Coral* (all forms mixed), CS: *Colonised Substrate* (*Dead Coral*, *Rock*, *Large Boulder*), SRU: *Rubble* and *Small Boulder*, SSA: *Sand*. *see Annex 5 for list of sites.

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Class Habitat	**Dominant type of bottom**	**Assigned % cover (index)**					**Most likely to be found***
		LC	**CS**	**SRU**	**SSA**	**SPA**	
C	Exceptionally high live coral cover	>75% (5)	<5% (none or present)	1-10% (1)	<5% (none or present)	Absent	Exceptional patches of reefs
I	Rubble	< 5% (none or present)	<5% (none or present)	>75% (5)	<5% (none or present)	Absent	Towards the reef crest and isolated reef patches (rubble dome)
D	Dominated by sand, with live coral cover	1-50% (1-2-3)	11-20% (2)	1-30% (1-2)	31-50% (3)	Absent	Typically deep sites in the lagoon or inner slope
A	Dominated by small boulder with live coral cover	11-30% (2)	<5%	50-74% (4)	<5%	<5%	Typically slope of a isolated reef patch
E	Dominated by rubble with pavement and small boulder	1-10% (1)	1-30% (1-2)	5-40% (1-2-3)	1-15% (1-2)	5-30% (1-2)	Reef flat, typically in transition between reef crest and reef flat and on the south tip of Abore.
J	Dominated by colonised substrate with high live coral cover	11-50% (2-3)	31-75% (3-4)	1-5% (1)	1-20% (1-2)	1-5% (1)	Reef flat, isolated coral patch with medium coral cover.
F+G	Dominated by colonised substrate (rock or dead coral encrusted), with low live coral cover	1-30 % (1-2)	31-75% (3-4)	5-30% (1-2)	1-20% (1-2)	1-20% (1-2)	Reef flat, isolated coral patch, with low to medium coral cover.
H	Dominated by pavement	1-15% (1-2)	1-20% (1-2)	1-30% (1-2)	1-10% (1)	30-100% (3-4-5)	Reef crest and transition with reef flat

Mis en forme : Centré

In terms of coral cover, the next step would be to find categories that would allow a finer classification of live coral cover. For example, we observed clear trends, 1) coral forms such as open branching coral around isolated reef patches in the lagoon and the site called "forest", 2) areas of the reef flat that were dominated by table coral or by columnar forms. These areas are usually large enough to cover around four pixels of the Quickbird or IKONOS high resolution image and could therefore be used for training image classification.

LIT and Habitat data gave very similar classes, given the fact that LIT transects were not conducted on very homogenous areas covered by rubble. This explained the presence of classes E and H on the habitat typology derived from Habitat-form data.

The similarity threshold for both methods of hierarchical clustering had to be different in order to obtain a similar level of habitat description. As a result, classes in the Habitat dendogram had a large standard deviation and were not as sharply defined as LIT classes. This is partly due to the number of categories that were taken into account for the clustering.

3.4. Classification of IKONOS Abore Reef image

A total of 15 habitats are used for the classification of Abore Reef, according to the combination of Habitat classes (eight from the cluster analysis) and the main different morphological zones (Reef flat, Inner slope, Lagoon). There were also habitats such as *Sand* which were not surveyed and therefore not included in the LIT and Habitat classes but which were added to the classification.

Table 5. Class labels used for the mapping of South Abore for each main geomorphological zones with corresponding LIT and Habitat classes and dominant bottom type. (*Coral dead encrusted/Rock: Coral Dead Encrusted and/or Rock*, *Rubble*: *Rubble* and *Small Boulder*) * either a class was not described by LIT or Habitat forms or there is a change in the class described in the Habitat classification.

	Class name on image classification	**Class**		**Dominant type of bottom**
		LIT	**Habitat**	
Reef flat	sand*			sand
	sand mixed	C	D	Dominated by sand, with live coral cover
	rubble mixed	D	E	Dominated by rubble with pavement and small boulder
	pavement mixed		H	Dominated by pavement
	coral dead encrusted/rock shallow	F+H	J, F+G	Dominated by colonised substrate
Inner slope	sand*			sand
	sand mixed	C	D	Dominated by sand, with live coral cover
	coral dead encrusted/rock shallow	F+H	J, F+G	Dominated by colonised substrate
	coral dead encrusted/rock deep	F+H	J, F+G	Dominated by colonised substrate
Lagoon	sand mixed shallow	C	D	Dominated by sand, with live coral cover
	sand mixed deep	C	D	Dominated by sand, with live coral cover
	sand and rubble mixed*		I+D*	Dominated by sand and rubble
	coral dead encrusted/rock shallow	F+H	J, F+G	Dominated by colonised substrate
	coral dead encrusted/rock deep	F+H	J, F+G	Dominated by colonised substrate
	live coral	A	C	Exceptionally high live coral cover

Habitat classes were more adapted than LIT classes to define classes for the image classification. Indeed more habitats were included in Habitat classes such as H and E (Habitat classification) which did not exist in the LIT habitat typology because no transects were carried out on these habitats.

Initially, we wanted to map the classes with medium to high coral cover (E+G and J in LIT and Habitat clustering respectively) since the goal of this project is to be able to identify variation of live coral cover. However we had to merge them with other classes for two reasons:

1/ there was no site with sufficiently high live coral cover (class A and C for LIT and Habitat cluster analysis respectively) (pixel wise) to train the supervised classification, except in the lagoon, however the area with high live coral only covered 4 pixels.

2/ live coral cover hardly ever occurred as the dominant category (class E+G and class J respectively) in an area or in an area large enough to differentiate on the image.

The overall classification of South Abore (Fig. 10) has 15 classes total, of which 3 (*Sand*, *Sand Mixed*, *Coral Dead and/or Rock*) are present in all three zones. Four classes have the same bottom type and are discriminated by depth (*Sand Mixed* shallow/deep and *Coral Dead and/or Rock* shallow/deep). Two classes were added to the original classes defined by LIT and Habitat cluster analysis:

1/ *Sand* with >75% sand which is easily visible on the image.

2/ *Sand and Rubble Mixed* which is defined by habitats where both class I and D (Habitat cluster analysis) are found in close proximity or where class D is present with very low live coral cover and high sand cover.

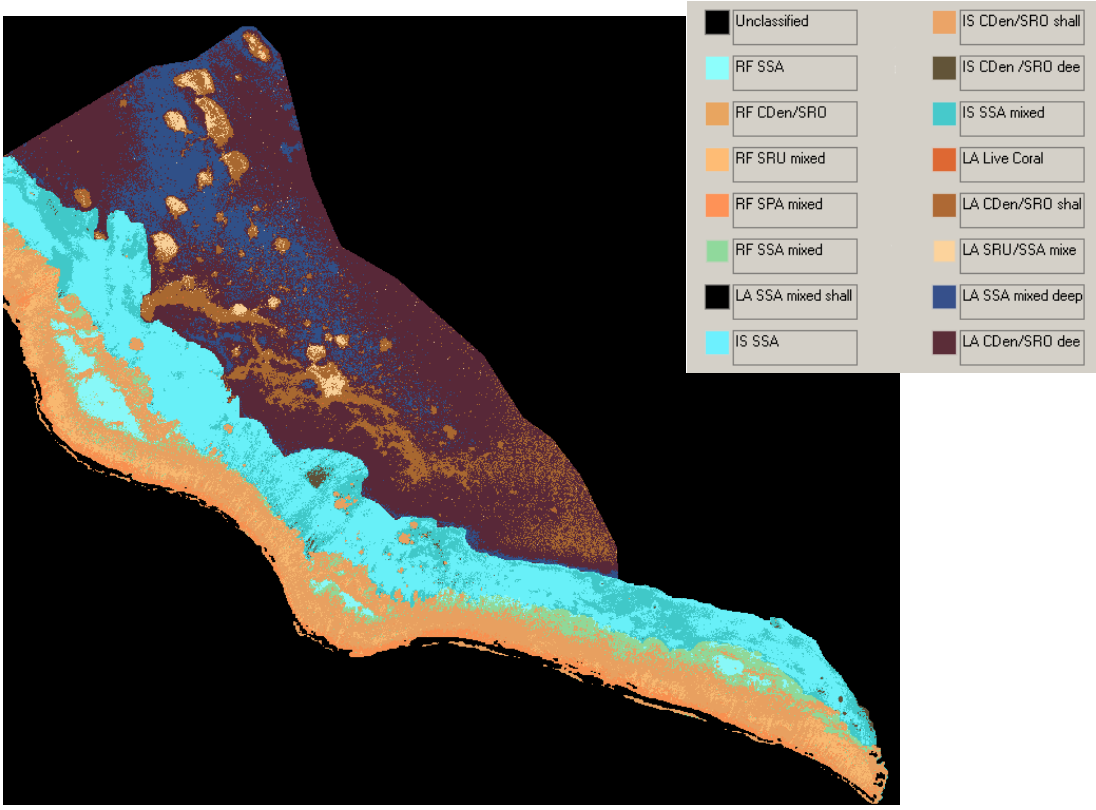

Fig. 10 Classification and legend of South Abore using ENVI Maximum Likelihood algorithm. RF: Reef flat, IN: Inner slope, LA: Lagoon, SSA: *Sand*, SRU: *Rubble*, CDen/SRO: *Coral Dead encrusted/Rock*.

Table 6. User and producer accuracies for the three geomorphological zones of South Abore. (Overall accuracy: 67.7%, kappa coefficient: 0.65). SSA: *Sand*, SRU: *Rubble*, SPA: *Pavement*, CDen/SRO: *Coral dead encrusted/Rock*.

	Class	**Producer Accuracy**		**User Accuracy**	
		(Percent)	(Pixels)	(Percent)	(Pixels)
Reef Flat (5 classes)	SSA	99	99/100	82	99/120
	SRU mixed	28	28/100	31	28/90
	SPA mixed	23	23/100	92	23/25
	SSA mixed	40	40/100	74	40/54
	CDen/SRO	65	65/100	27	65/235
Inner Slope (4 classes)	SSA	100	100/100	85	100/118
	CS shallow	97	97/100	100	97/97
	SSA mixed	81	81/100	68	81/118
	CDen/SRO deep	32	32/100	97	32/33
Lagoon (6 classes)	CDen/SRO mixed deep	85	81/95	85	81/95
	CDen/SRO shallow	89	89/100	70	89/127
	SRU/SSA mixed shallow	74	74/100	91	74/81
	SSA mixed	65	57/87	93	57/61
	Live Coral	100	08/08	67	8/12
	SSA mixed shallow	0.00	0/1	0.00	0/0

The overall accuracy of the classification and producer and user accuracies for each class are given in Table 6. The overall accuracy (67.7%) and Kappa analysis (0.65) is moderately good compared to the literature. However, when looking at producer and user accuracies, we note that "Reef flat" classes are particularly low (*SRU mixed*: 28% and 31% producer and user accuracy respectively; *SPA mixed*: 23% producer accuracy; *SSA mixed*: 40% producer accuracy). Low producer accuracy indicates that the probability that the pixels in a class have been correctly classified is low. For example, there is a 23% probability that the pixels in *SPA mixed* (Reef flat) have been correctly classified. However there is a 92% chance that the areas identified as belonging *SPA mixed* will actually belong to that class. Low user accuracy indicates that there is a low probability that areas are labelled correctly. For example there is a 27% chance that an area classified as *Coral dead encrusted/Rock* on the reef flat actually belongs to that class.

This poor result can be easily explained. Indeed we quickly noticed in the field that the IKONOS image patterns did not correspond to what we observed under water, especially along the reef flats. We processed IKONOS data while waiting for the completion of a more recent Quickbird image. This Quickbird image was finally acquired, but only at the end of this work which was completed in February 2005. The new image allowed us to compare both images (Fig. 11 and Fig. 12). The structure of the reef flat has visibly changed between 2002 and 2004. Areas that were dark and that visually could be interpreted as either live coral and rock or coral dead encrusted and rock now have a lighter colour and correspond to what was observed in the field, i.e. rubble and pavement. This difference due to changes that have occurred between image acquisition and collection of field data explains most of the misclassification along the reef flat.

Fig. 11 and 12 IKONOS (left) and Quickbird (right) image of the same area on South Abore. The outlined areas changes in the structure of the reef: the transverse stripes have disappeared and the darker area (live/dead coral) is now lighter (rubble/pavement).

These visible changes and the low accuracy found on the reef flat imply that a new classification of the more recent image should have much higher producer, user and overall accuracy.

4. Perspectives

The image used during field work was an IKONOS image taken in 2002 before major events such as the cyclone Erika occurred. When observation in the field did not match what was expected from the image, we suspected that major changes had occurred, in particular in the structure of the reef crest and reef flat and in live coral cover. After acquiring new Quickbird images, these changes became visible even to the naked eye by comparing both images (Figure 11).

Work will therefore be carried out on the new Quickbird image and involve the analysis of changes detectable by comparing the IKONOS and Quickbird image. First, a final classification of Abore reef will complete the work started for this project. This should allow a finer classification which will include classes dominated by live coral cover. Then we will compare the two images to detect changes, aiming in particular to finding areas where live coral cover has been altered.

Habitat descriptions and the classification of Abore reef will also be used in combination with fish data collected on the reef. We will try to find a correlation between the classes defined by the image classification and the characteristics of fish population in those areas (diversity and abundance). It would also be interesting to see if fish population has responded to the changes observed on the images of habitats, but the availability of the right historical data needs to be assessed.

5. Final recommendations

A comparison of the LIT data and Habitat data showed that there was large variation in the data collected at the beginning of the project. The main reason for this was that observers were not yet efficient in the methods and errors were evident. This data was not used in the final analysis. We also noticed that there was more discrepancy in the data when there were more observers, especially at early stages. In order to minimize data loss and increase training efficiency, it is important that:

- Observers are chosen prior to the field work and do not vary throughout.
- A short training period is necessary and data should systematically be discarded.
- Training should take place both inside and outside water.
- Coral forms, use of index and use of the habitat form should be clear.

Field work is always more difficult when the equipment is not optimal for the targeted environments. This was often the case for this project. The reef is often exposed to strong tidal currents. Due to restricted availability of the boat, it is not possible to choose the days and time to work around the tides. Furthermore, the R/V CORIS can not approach the reef crest or reef flat due to the shallow water in these zones. The observers were exposed to situations where they have to swim against the strong current. The underwater scooter was of great help, unfortunately, they have a short autonomy, lasting only about one hour.

Therefore, we suggest the acquisition and use of a very shallow water, fast, motorized, two to three-seats boat with turbines (jet-boat, jet-ski). This would reduce dramatically loss of time travelling to and from the reef crest and on the reef flat but most importantly it would improve safety on the water.

It would have been interesting to keep systematically a photographic record of habitats to document them and also for comparison in time. This will be developed in the final conclusions of the reef-lagoon Habitat studies funded by ZONECO, to be available later in 2005.

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Figures, Tables and Annex

Figures

Tables

Appendix

APPENDIX 1

Campaign |________________| **Site** |___________________________| **Diver** |__|__| **Transect** |__|__|__|
D |__|__|/|__|__|/20|__|__| **Lat.**|__|__|°|__|__|,|__|__|__|' **Long.**|__|__|__|°|__|__|,|__|__|__|' **WT** |__|__|__|

Start time: |__|__| :|__|__| End time: |__|__| :|__|__| Secchi disc visibility |__|__| m Left ☐ Right ☐

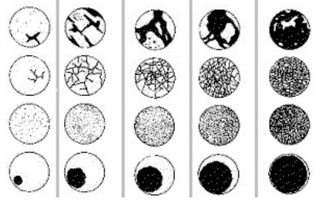
Primary reef: Coastal ☐ Lagoon ☐ Back ☐ Outer ☐ **Secondary Reef:** Coastal ☐ Lagoon ☐ Back ☐ Outer ☐

	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

draw profile including estimate of slope in degree
Flat ☐ Floor ☐
Gentle slope ☐ Steep slope ☐

Remarks: Use percentage or ranks

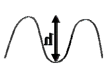
1	2	3	4	5
1-10%	11-30%	31-50%	51-75%	76-100%



	Quadrat limit 0	5	10	15	20	25	30	35	40	45	50
	Depth of transect line (m)										
	Topography (meters)										
	Complexity (1-5)										
Level 1	Hard substrate										
	Soft substrate										
(Level 2) Abiotic	Rocky subst./pavement										
	Mud										
	Sand										
	Rubbles										
	Small boulders (<30cm)										
	Large boulders (< 1m)										
	Rocks (> 1m)										
(Level 2) Hard coral status	Live										
	Bleaching										
	Dead bare (recently dead)										
	Dead encrusted (old dead)										
	Dead fleshy algae covered										
(Level 3) Hard coral shape live/dead	Massive										
	Av. Massive colony size										
	Compact Branch										
	Av. Branch. colony size										
	Open Branch										
	Av. Branch. colony size										
	Encrusting										
	Av. Encrusting colony size										
	Tabulate										
	Av. Tabulate colony size										
	Foliose										
	Digitate										
Level 2 other	Sponge										
	Soft coral										
Level 2	Macro-algae (soft to touch)										
(Level 2) Plant & algae	Turf (filaments)										
	Calcareous algae)										
	Crustose coralline										
	Cyanophycae										
	Seagrass										
Level 3	Silt covering coral										

Branching : has secondary branching
Digitate : no secondary branching
Hard coral (dead & live) : Coral attached to substrate with an identifiable shape (otherwise it's abiotic)
Compact/open branch : cannot/can see through the colony
Rubble : any piece or whole coral colony of any size that is not attached to substrate
Topography (regardless of surface orientation):
1 : no relief, 2 : low (h<1m), 3: medium (1<h<2m)
4: strong (2<h<3m), 5: exceptional (h>3m)
Complexity (quantity and diversity of holes and cavities): 1: none, 2: low, 3: medium, 4: strong, 5:exceptional
Abundance estimated relative to the category (e.g. 30% live, 100% massive means 100% of the 30% live coral cover is massive)
Turf, crustose algae: may cover dead old substrates

topography



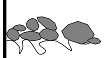
Complexity

1 : none

2 :low

3 : medium

4 : strong



5:Exceptional

APPENDIX 2

Date	Site	Diver	#	Lat/Long

Quadrat limit 0 5 10 15 20 25 30

		Depth of transect line (m)						
		Topography (m)						
		Complexity (1-5)						
100%		Soft Substrate *						
	100%	Mud						
		Sand						
		Rubble						
		Small Boulder (<30cm)						
		Hard Substrate*						
	100%	Pavement						
		Rocky floor						
		Large boulder (>30cm)						
		Rock						
		Coral Live						
		Coral Bleached						
		Coral Dead Bare						
		Coral Dead Encrusted						
	Coral Live 100%	Massive						
		Av. Massive colony size						
		Sub-Massive						
		Av. Sub-Mass colony size						
		Compact Branch						
		Av. Compt Branch colony size						
		Open Branch						
		Av. Open Branch colony size						
		Tabulate						
		Av. Tabulate colony size						
		Digitate						
		Av. Digitate colony size						
		Foliose						
		Av. Foliose colony size						
		Encrusting						
		Av. Encrusting colony size						
		Millepora sp.						
% total cover		Other Live Biotic cover						
	100%	Sponge						
		Soft coral						
		Other						
% total cover		Plants&Algae cover						
	100%	Macro-algae						
		Turf						
		Calcareous algae						
		Crustose coralline+ Encrusting Algae						
		Cyanophycea						
		Seagrass						

Depth of transect: average depth from the surface to the top of the structure

Topography: average height of the structure (highest point to the lowest point)

Complexity:

1: none	2: low
3: medium	4: strong
5:Exceptional	

Measures: Use indices, use "X" to iindicate cover<1%

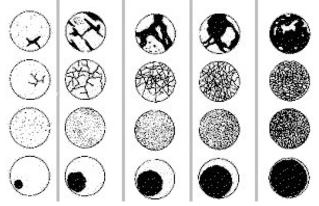
100% : the sum of the categories should equal 100%

***** the sum of hard and soft substrate should equal 100%

% total cover: indicates the % cover over the entire the 5*5m² of transect

Remarks: Use Index. Use "X" to indicate % cover <1%

1	2	3	4	5
1-10%	11-30%	31-50%	51-75%	76-100%



Rocky floor: surface is more rugged than pavement but complexity is still between 0 and 1

Rock: unidentifiable dead coral; can have any structure and any complexity from 1 to 5

Coral Dead Bare: recently dead coral

Coral Dead Encrusted: Coral colony still has its original shape but can be covered in turf, coralline or encrusting algae, fleshy algae, etc.

APPENDIX 3
Analysis of Indexes

1/ Replace index by the minimal value of the % interval:

1	2	3	4	5
1 %	11 %	31 %	51 %	76 %

Add categories over the length of the transect. If the sum >100% => Problem => check data.

3/ Replace index by the median value of the % interval:

1	2	3	4	5
5,5 %	20,5 %	40,5 %	63 %	88 %

Add categories over the length of the transect. If the sum >=140%=> Problem => check data.

4/ Once corrected, for each level of substrate (the sum of the cover should be 100%) divide the value of the median of each category by the sum of all median (previously calculated) and multiply by => corrected % values.

5/ Average by transect and correct again (4/).

APPENDIX 4
List of LIT sites by class

The first name indicates the reef structure:
- Ptte "patate": Reef patch
- Plt int "platier interne": Reef flat
- Lag "lagon": Lagoon

The second name gives more precision on the location in regard to the reef struture:
- Ptte Plt "patate platier": reef flat on isolated reef patch
- eperon sillon: transverse stripes
- Ptte lagon "patate lagon": reef patch in the lagoon
- crête: crest

The rest gives further indication of the location, nature of dominant substrate, orientation etc...
- N: north
- S: south, milieu: middle
- bord: edge
- limit: boundary
- comp "compact": compact reef
- SRU: rubble, SSA/ sand
- CDen: coral dead
- Br: branching
- Ta: table coral
- SRO: rock

The date of data collection is indicated at the end of the name of the sites.

Site	Class	Site (continued)	Class
Ptte 4 lagon Br 1712	A	Ptte1 lagon bourrelet Br 2312	H
Plt1 int align transv RU 1512	B	Ptte2 lagon pnte 2312	H
Lag const cora disp 1711	C	Ptte 6 lagon bord eperon sillon 2312	H
Pnt1 int prof Br 2510	C	Ptte 7 lagon bord SSA Br 2312	H
Plt1 int bord 2701	C	Ptte 8 lagon SRO Ta 2312	H
Ptte 1 lagon pnte constr coral dispersé 1712	D	Plt 2 int limite 1712	H
Plt3 int limite 1711	D	Ptte 2 lagon bord 1712	H
Plt2 int RU 1711	D	Ptte1 pnt int 0212	H
Plt3 int align transv Cden 2710	D	Ptte2 pnt int 0212	H
Plt1 int align transv 2510	D	Ptte3 pnt int 0212	H
Ptte2 de Plt int 2510	D	Plt3 int comp 0212	H
Plt3 int patées dispersés 1512	D	Pnt1 int prof Br 2710	H
Plt4 int align transv 1512	D	Pnt2 int prof Br 2710	H
Plt1 int crête 1512	D	Pnt3 int prof Br 2710	H
Ptte 3 lagon bord eperon sillon 1712	E	Pnt1 Ptte 2710	H
Plt5 int limite Br 1711	E	Plt2 int align transv 2510	H
Plt Ptte N 2701	E	Ptte1 de Plt int 2510	H
Ptte 5 lagon bord SRO SSA 2312	F	Plt2 int crête 1512	H
Plt 1 int comp 1712	F	Ptte 2 lagon bord 1512	H
Plt4 int limite Br 1711	F	Ptte 3 lagon bord 1512	H
Plt7 int limite Br 1711	F	Ptte 4 lagon milieu 1512	H
Plt2 int align transv Cden 2710	F	Plt int bord 2601	H
Plt2 int align transv RU 1512	F	Plt int alignement transv 2601	H
Ptte 1 lagon milieu RU 1512	F	Ptte Plt1 2601	H
Plt2 int bord 2701	F	Ptte Plt2 2601	H
Plt3 int bord 2701	F		
Plt1 int comp 1012	G		
Plt2 align transv 1012	G		

APPENDIX 5
List of Habitat sites by class

The first name indicates the reef structure:
Ptte "patate": Reef patch
Plt int "platier interne": Reef flat
Lag "lagon": Lagoon

The second name gives more precision on the location in regard to the reef struture:
Ptte Plt "patate platier": reef flat on isolated reef patch
eperon sillon: transverse stripes
Ptte lagon "patate lagon": reef patch in the lagoon
crête: crest

The rest gives further indication of the location, nature of dominant substrate, orientation etc...
N: north
S: south,
milieu: middle
bord: edge
limit: boundary
comp "compact": compact reef
SRU: rubble, SSA/ sand
CDen: coral dead
Br: branching
Ta: table coral
SRO: rock

The date of data collection is indicated at the end of the name of the sites.

Site	Class	Site (continued)	Class
Ptte3 pnt int 0212	A	Plt8 int RU 1012	G
Ptte2 pnt int 0212	B	Plt4 int limite Br 1711	G
Ptte 4 lagon Br 1712	C	Plt2 int align transv Cden 2710	G
Plt Ptte N 2701	C	Plt3 int align transv Cden 2710	G
Lag 10 Const coral SSA 1512	D	Pnt Ptte 2710	G
Lagon cons coral dispersées 1711	D	Pnt1 int prof Br 2710	G
Plt5 int limite Br 1711	D	Plt1 int align transv 2510	G
Ptte 1 lagon pnte constr coral dispersé 1712	E	Pnt1 int prof Br 2510	G
Plt2 int RU 1711	E	Plt3 int dalle 1012	H
Plt3 int limite 1711	E	Plt1 int comp 1012	H
Crête dalle 2710	E	Plt12 int RU 1012	H
Plt2 int RU 2710	E	Plt6 int RU 1012	H
Plt int dalle 2510	E	Crête3 dalle 1012	H
Plt int RU 2510	E	Plt int align transv 2710	H
Ptte 1 lagon bourrelet Br 2312	F	Plt int dalle 2710	H
Ptte 5 lagon bord SRO SSA 2312	F	Crête dalle 2510	H
Ptte 6 lagon bord eperon sillon 2312	F	Plt11 int RU 1012	I
Ptte 7 lagon bord SSA BR 2312	F	Plt13 int limite 1012	I
Ptte 8 lagon SRO Ta 2312	F	Plt1 int RU 2710	I
Ptte2 lagon pnte 2312	F	Ptte4 lagon milieu 2312	J
Ptte 2 lagon bord 1712	F	Plt 2 int limite 1712	J
Ptte1 pnt int 0212	F	Lag 5 Const Coral Br 1512	J
Plt2 align transv 1012	F	Lag 7 Const Coral Br 1512	J
Plt4 int align transv 1012	F	Lag 8 Const Coral Br 1512	J
Crête2 dalle 1012	F	Lag1 const coral prof 1512	J

Plt1 int bord 2701	F
Plt3 int bord 2701	F
Plt int bord 2601	F
Plt int eperon sillon 2601	F
Ptte1 Plt 2601	F
Ptte2 Plt 2601	F
Plt 1 int comp 1712	G
Ptte 3 lagon bord eperon sillon 1712	G
Plt int crête 1512	G
Plt1 int align transv RU 1512	G
Plt2 int align transv RU 1512	G
Plt3 int patées dispersés 1512	G
Plt4 int align transv 1512	G
Lag 9 Const Coral Br 1512	G
Plt3 int compact 0212	G
Crête Plt3 0212	G
Plt5int RU 1012	G
Plt7 int RU 1012	G

Lag2 const coral prof 1512	J
Lag3 const coral prof 1512	J
Lag4 const coral prof 1512	J
Ptte 1 lagon milieu RU 1512	J
Ptte 1 pnte 1512	J
Ptte 2 lagon bord 1512	J
Ptte 2 pnte 1512	J
Ptte 3 lagon bord 1512	J
Ptte 4 lagon milieu 1512	J
Lag 6 Const Coral Br 1512	J
Plt1 int 0212	J
Crête dalle 1012	J
Plt10 int align transv 1012	J
Ptte Lagon 1012	J
Plt7 int limite Br 1711	J
Pnt2 int prof Br 2710	J
Plt2 int bord 2701	J