Payments for Marine protected area ecosystem services in the Caribbean (CARIPES)

Report 2.2 – Ecological assessment and health status indicators

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1. Tropical marine ecosystems

Three major tropical marine ecosystems are described: mangroves, seagrass and coral reefs. However, more categories can be found depending on the nature of the sea bottom and the biological community composition. More ecosystems can be defined as algal communities, sponges and gorgonians assemblages, mixed communities (small coral construction with sponges, gorgonians and green calcareous algae surrounded by seagrass). The classification depends on specific attributes that help characterize the biological assemblages.

1.1. Attributes

A set of attributes has been selected for ecosystem communities and biodiversity, health and resilience. Each attribute may have more than one measure associated with it.

1.1.1. Biological/ecological features

1.1.1.1. Communities

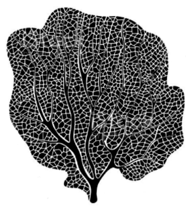
- *Coral communities*

Coral reefs are underwater limestone bioconstructions built by living organisms. Coral reefs can cover large areas along the coast or form atols surronding ancient volcanic island that disappeared in goelogical subduction areas. Corals play a major role in forming the skeleton of the reef, and encrusting calcareous algae consolidate the construction. Other organisms are involved, but in a minor way. Although they occupy less than 0.25% of the global marine waters, coral reefs are home to more than a quarter of all marine known fish species (Moberg and Rönnbäck 2003). Nearly 5000 species of fish have been identified and 2500 species of corals: reefs are habitat to high level of biodiversity (Harborne et al. 2006). Corals contribute to the carbon cycle: a healthy reef stores carbon, while a degraded reef may release carbon in the environment (German et al., 2004). The reefs also contribute to coastal protection. The erosion of the coastline is less important in areas where reefs are of good quality (Sheppard et al. 2005). Corals also have utility in the medical sector (new active compounds, surgical bio-implants). Because of their existence, they constitute a specific economic resource for the fisheries sector (biomass), and tourism, especially scubadiving.

- *Seagrass*

Seagrass ecosystems are underwater meadow of phanerogams (flower plants) adapted to the marine environment. Usually situated between reefs and mangroves in tropical zone, they contribute to sediment retention between the roots of the plant, which consolidates the loose substratum. Seagrass meadows are important food resources for herbivorous organisms. They also function as nursery for a large variety of organisms, especially juveniles' fish (Cocheret de la Morinière et al. 2002).

- *Sponges and gorgonians*

In shallow coastal waters, especially in disturbed areas (waves, currents), sponges and gorgonians communities develop and consitute a specific habitat different from coral communities. In these assemblages, corals are a minor biological component / category.

- *Algal communities*

According to the shift phase theory, confirmed by many observations in tropical areas, algae communities tend to replace coral communities in reefs previously dominated by corals (Hughes et al. 2007). As a conqesuence, a new benthic category can be described as algal community. The assemblages of marine algae gather several species, but dominant genus can often be recorded as Sargassum, Dictyota, or Lobophora. Algal communities can cover large areas in coastal waters.

- *Mixed communities*

Mixed community, combining seagrass and coral communities, can be considered a "buffer" zone between the two types of biological communities and not a biotic community in itself. This composition, albeit weakly represented, gather specific populations (fish, corals) specific of the two communities. Mixed communities are generally located in the shallows, and in lagoons protected by barrier reefs, or in bays.

- *Mangroves*

Mangrove forests are specific plant formation located in tropical and subtropical regions. These submerged forests are composed of tree species adapted to the marine environment, and especially the alternance of low and high tides. The tree species belong to the mangles trees.
The mangrove is a specific habitat for many terrestrial and aquatic species. It provides nursery areas for many reef fish juveniles who find abundant food sources and refuges betwwen the roots. The biomass of reef fish is more important if reefs are associated with mangrove areas (Mumby et al. 2004).
Mangrove contributes in some processes to natural purification of freshwater from adjacent rivers. The roots limit sediment transportation and deposition on seagrass and offshore coral reefs (Harborne et al. 2006). Corals need clear water to developp and grow. Hypersedimentation associated to runoff events can cause rapid degradation of ecosystems.
Mangrove also are involved in nutrient cycling of nitrogen, carbon (Bosire et al. 2008). Like any forest, mangrove is a carbon sink, which contribute to fight against greenhouse effects. Mangroves provide coastal protection against sea erosion (Thampanya et al. 2006), and act as a buffer in case of cyclones or tsunami (Vermaat and Thampanya 2006).

1.1.1.2. Biodiversity

Biodiversity is the variability among living organisms from all sources, including, inter alia [among other things], terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems (United Nations convention on Biological Diversity definition).

Biodiversity is often considered as a key criterion in evaluating the status of ecosystems. High biodiversity is correlated to functional redundancy in the ecosystem. Functional diversity, more than biodiversity itself (as the number of species), will define the resilience capacity of the ecosysem. If a key species disppear, it will be replaced by another functionnaly redundant species, not changing the stability of the system.
Species composition remains one of the principal criteria to describe communities.

1.1.1.3. Dynamic and vulnerability

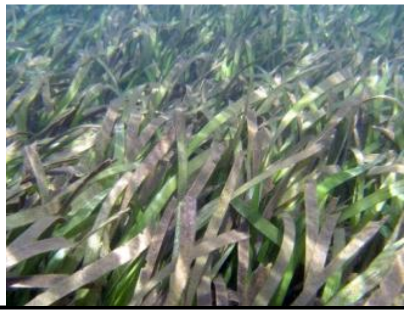
Ecosystems are fluctuating species assemblages driven by environmental processes. The stability of the system depends on species interactions and environmental quality. Disturbances on one category might alter the global organization wich in turns can drive the

stable system to another stable level. Vulnerabilty can be then considered as an ecological level at wich ecosystem balance can be rapidly perturbated. Even if ecosystems are dynamic systems, interactions reach an instable equilibrium subjected to transitional phases.
Species constituting ecosystems can be assigned to functional types defining a number of functional groups in a system. Functional diversity of an ecosystem is then correlated with the number of functional groups or the number of members of each functional group. High functional diversity emphasises that ecosystem are more resistant to environmental changes and stress. Changes in species diversity, i.e. the number of species in the ecosystem, could then modify the adaptive capacity of the ecosystem to environmental changes.
Modifications of biodiversity and ecosystem functionality have an impact on the production of ecosystem services and the direct and indirect economic activities that depend on these services. Disturbed areas are more vulnerable to changes.

1.1.2. Ecosystems' health status

Coral reefs, seagrass and mangroves health status assessment requires specific approaches to each ecosystem. Health statuses are evaluated using quantitative and objective methods, and coded to weigh ecosystem services.
The loss of biodiversity and species density, necrosis or diseases, presence of indicator species, increase of tolerant species, recruitment rates, are parameters considered for estimating the degradation of benthic biological communities (Jameson et al. 1998; Linton and Warner 2003). Specific monitoring protocols (GCRMN, CARICOMP, ReefCheck) gather measurements to assess these parameters. A rapid visual estimation has been developed for the Caribbean region. The scale of degradation, based on simple descriptors, is only qualitative, applicable to coral communities and seagrass. It is based on three criteria: coral colony diseased (or density plants in seagrass beds), occurence of macroalgae and hypersedimentation. Four statuses are proposed for each of the two ecosystems: very good condition, good condition, degraded condition and very degraded state (Table 1).

Table 1. Health statuses are proposed for coral reefs and seagrasses ecosystems in the Caribbean.

Health status	Coral reefs	Seagrass beds
1 = very good	No signs of disease - No macroalge – Low cover of turf algae 	Strict Thalassia testudinum 
2 = good	Few signs of disease on corals – few macroalgae and/or few particles 	Mixed T.testudinum and Syringodium filiforme or strict S. filiforme 
3 = degraded	Corals with necrosis and algal assemblage dominated by macroalgae and / or strong hypersedimentation 	Seagrass invaded by soft macroalgae and or sparse plants 
4 = very degraded	Most corals are dead, habita invaded by macroalgae or completely covered with sediment 	Very sparse seagrass whatever the species or silt up 

1.1.3. Resilience and resistance

Resistance (ability to withstand change) and resilience (ability to recover from change) are two concepts that can be applid to coral reef communities. Disturbance and community stability are related, as stability is defined after community changes in response to disturbance (Rykiel 1985). The definition from in which stability is comprised of resistance and resilience, two quantifiable metrics that are useful for comparing community disturbance responses. Resistant systems appear more persistent and less variables because they change less under a given disturbance. Here, resistance is defined as the degree to which a community is insensitive to a disturbance, and resilience is the rate at which a community returns to a pre-disturbance condition. A related concept, sensitivity, is the inverse of resistance and defined as the degree of community change following a disturbance. Both resistance and resilience are usually quantified in relation to a community's level of intrinsic variability.

1.2. Patterns of change in coral reef communities in the Caribbean

1.2.1. Introduction

Four long-term monitoring sites were selected in Martinique (Pointe Borgnesse, Fond Boucher, Ilet à rats, Jardin Tropical) with very different environmental characteristics. Ilet à rats is on the Atlantic side and shows a reasonable balanced development. Grazing pressures on the 4 sites differ. One site shows a progressive degradation of the reef (Pointe Borgnesse), one site shows recovery after degradation (Jardin Tropical), and one site shows a very variable development (Fond Boucher).

We analysed the changes in the major benthic categories'cover (corals, macro-algae, turf algae, cyanobacterial mats, crustose coralline algae, and sponges) on each site. Beside these individual characteristics, we also looked at the community changes and we used multivariate control charts to test when the community becomes significantly different from the first year, which we used as a baseline (assuming that this was a relatively undisturbed condition).

1.2.2. Materials and methods

Individual benthic categories are described by Generalized Additive Models (GAMs, (Wood 2006). The combined development based on these 6 categories are described by non-metric Multi-Dimensional Scaling (Kruskal 1964b) and Multi-Variate Control Charts (Anderson and Thompson 2004) were used to calculate when a community became significantly different from its state at the first year of assessment. All calculations were done using the freely available software R (version 3.2.3, R Core Team, 2015). GAMs were calculated using package mgcv (Wood 2006), nMDS with package vegan (Oksanen et al. 2007), and multivariate control charts with R-code written by Erik Meesters.

1.2.3. Results and discussion

Benthic categories per site

Results of the regressions are shown in **Table 2**. Most regressions are highly significant and the regression explains much of the variation in the data. Low percentages cover and high variability in turf algae, cyanobacteria, and coralline algae and sponges on Jardin Tropical led to non-significant smooths. Furthermore smooths can be significant, but not give a clear direction of the trend or only show a clear trend for part of the time.

Table 2. GAM results. P-value of the estimated smoother, R^2, adjusted R^2, and estimated degrees of freedom of the smoother.

site	Category	p-value	R^2	R^2.adj	edf
PB	Corals	<0.001	0.968	0.954	6.095
PB	Macro-algae	0.001	0.667	0.606	3.066
PB	Turf algae	0.067	0.578	0.419	5.47
PB	Cyanobacteria	0.014	0.556	0.465	3.398
PB	Coralline algae	0.001	0.848	0.732	8.64
PB	Sponges	0.004	0.662	0.567	4.392
FB	Corals	<0.001	0.926	0.877	7.548
FB	Macro-algae	0.011	0.623	0.52	4.078
FB	Turf algae	0.004	0.759	0.647	6.043
FB	Cyanobacteria	0.01	0.805	0.654	8.277
FB	Coralline algae	<0.001	0.893	0.811	8.239
FB	Sponges	<0.001	0.918	0.879	6.098
IR	Corals	0.001	0.914	0.832	7.769
IR	Macro-algae	0.006	0.886	0.767	8.153
IR	Turf algae	0.314	0.067	0.005	1
IR	Cyanobacteria	0.989	0	-0.067	1
IR	Coralline algae	0.013	0.874	0.732	8.446
IR	Sponges	0.013	0.847	0.712	7.527
JT	Corals	<0.001	0.864	0.825	3.116
JT	Macro-algae	<0.001	0.967	0.941	6.052
JT	Turf algae	0.073	0.6	0.461	3.614
JT	Cyanobacteria	0.634	0.018	-0.058	1
JT	Coralline algae	0.396	0.062	-0.012	1.022
JT	Sponges	0.391	0.239	0.115	1.954

Site Pointe Borgnesse

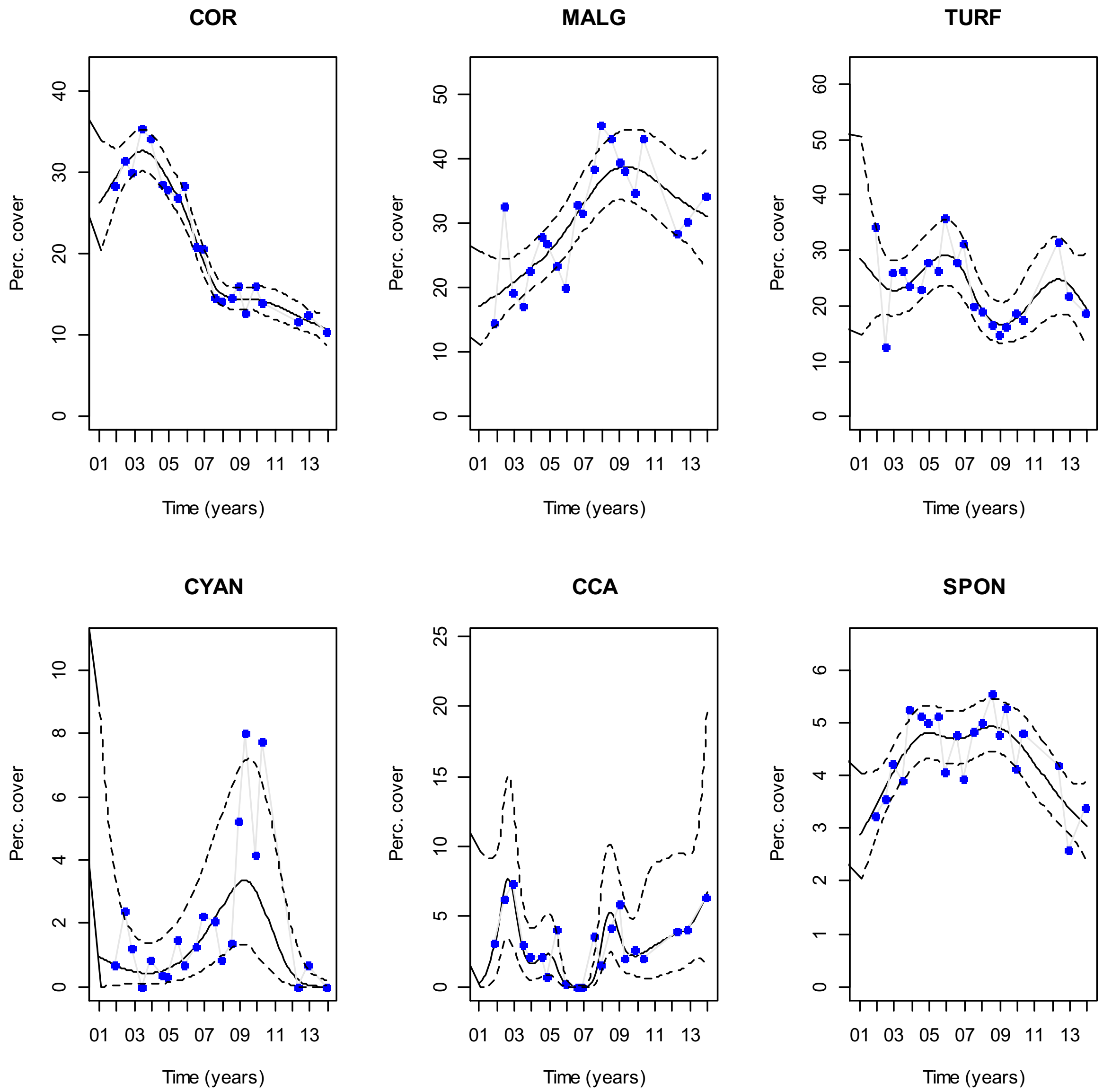


Figure 1. Individual benthic categories (corals, macro-algae, turf algae, cyanobacterial mats, crustose coralline algae, and sponges) in Pointe Borgnesse. Note different y-axis scales on different graphs.

Pointe Borgnesse is a community that is characterized by a gradual loss of living coral. From 2003 to 2007 the decrease in cover is steep, but after 2007 it slows down. Macro-algae increase rapidly during the period of fast decrease in living corals and appear to decrease a little bit recently stabilizing around 30% cover. The turf algae have decreased from around 30 at the start to around 20% in 2013. Total living cover is reduced from 85 to 73% leading to an increase of rubble and sand of about 15%, now totalling almost 30%. Cyanobacteria, sponges and crustose coralline algae are relatively unimportant and cover estimates are more variable.

Site Fond Boucher

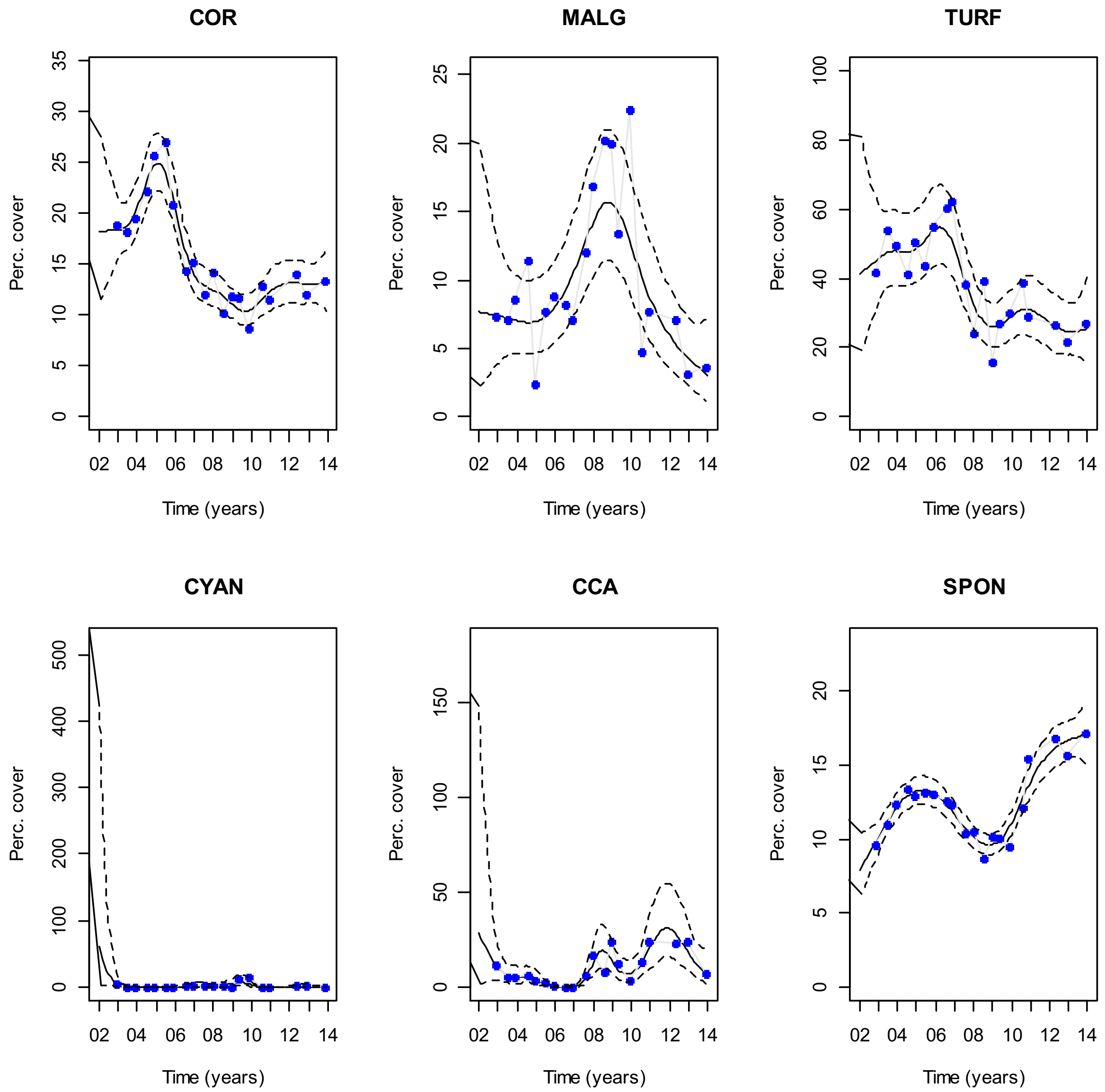


Figure 2. Individual benthic categories (corals, macro-algae, turf algae, cyanobacterial mats, crustose coralline algae, and sponges) in Fond Boucher. Note different y-axis scales on different graphs.

At Fond Boucher, the pattern of change in corals and macro-algae is similar to Pointe Borgnesse. The trend in turf algae is also similar, but values are more extreme and cover changes from about 50% at the start to 25% at the end of 2013. Coral cover is similar to Pointe Borgnesse, but macro-algae decrease sharply at the end of the series and are almost absent in 2013. It's a shallow site and macro algae can be removed by waves. Density of grazing urchins is high and they probably prevent the macro-algae from getting established again. Cyanobacteria and crustose corallines are virtually absent, but sponges increase at the beginning of the period and after 2010. Living cover decreases from 96 to 67% due to an increase in rubble, sand and bare substrate. The dominant benthic categories are now turfs and sponges.

Site Ilet à rats

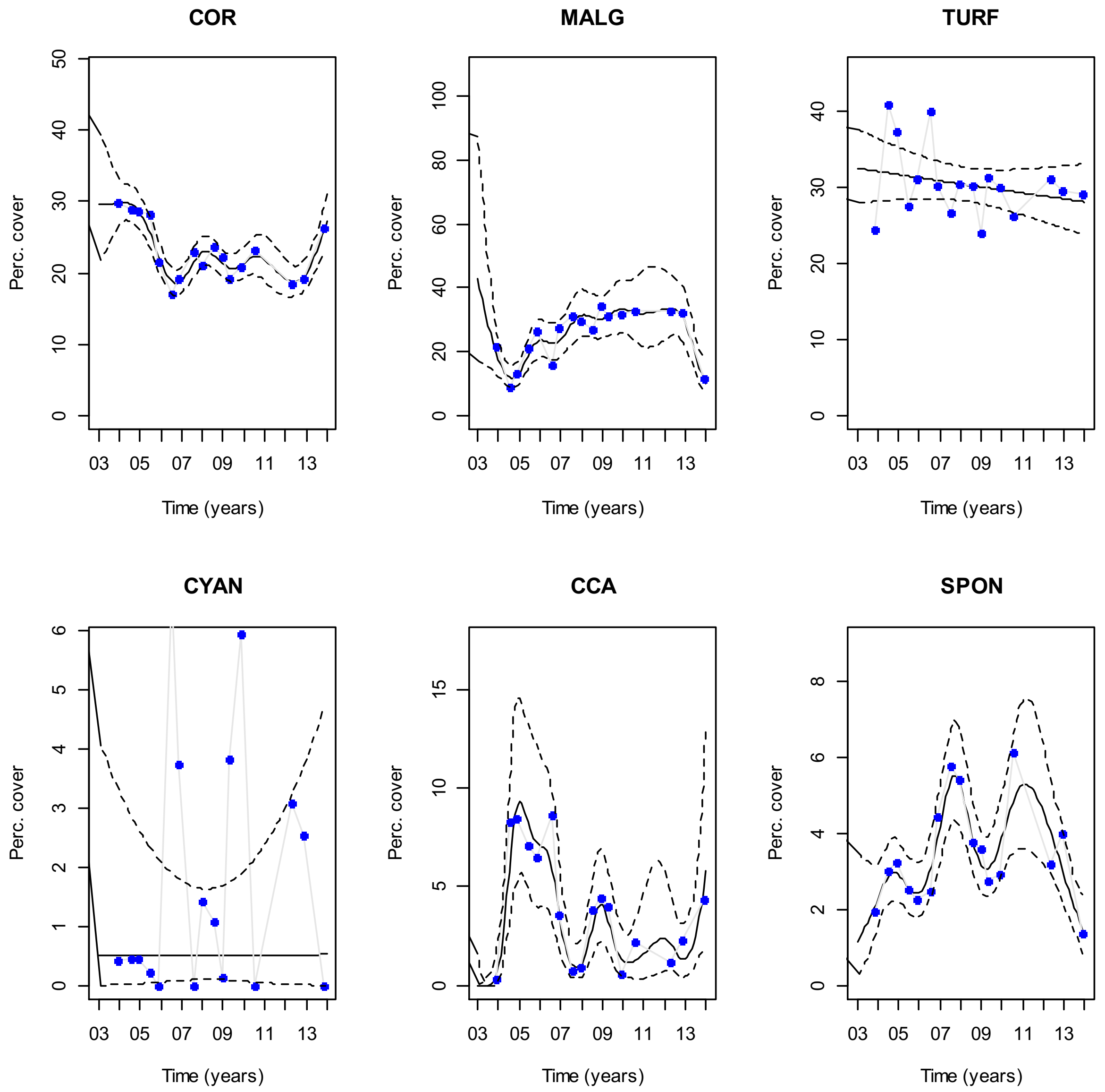


Figure 3. Individual benthic categories (corals, macro-algae, turf algae, cyanobacterial mats, crustose coralline algae, and sponges) in Ilet à rats. Note different y-axis scales on different graphs.

Ilet à rats shows relatively little change. Coral cover decreased from 2005 to 2007, but went up and down again and increased recently to almost similar values as the start. There was a slow increase in macro-algae, but recently their cover has decreased to the lowest values in the time series. It appears that the site is quite stable.

Site Jardin Tropical

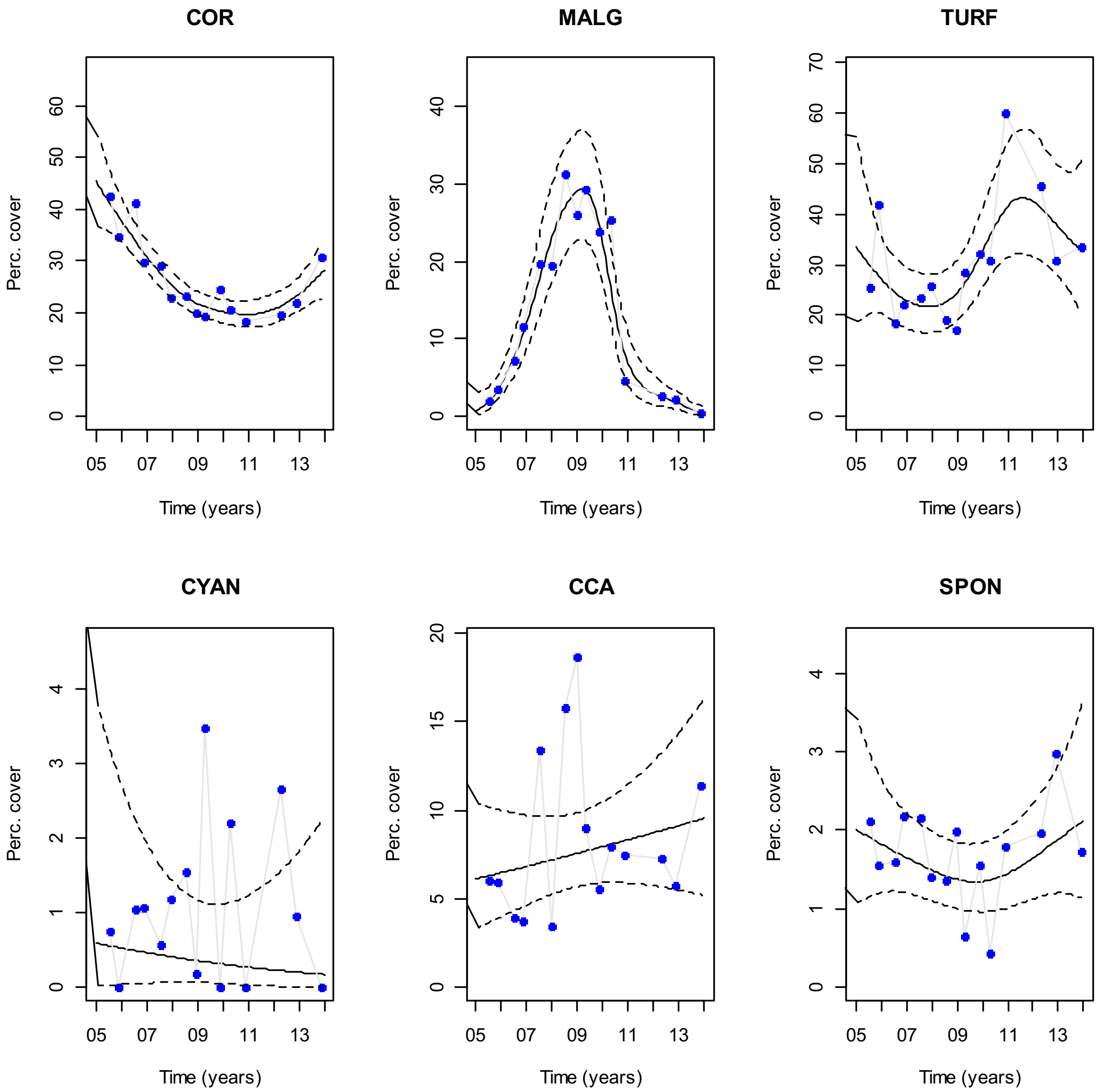


Figure 4. Individual benthic categories (corals, macro-algae, turf algae, cyanobacterial mats, crustose coralline algae, and sponges) in Jardin Tropical. Note different y-axis scales on different graphs.

Jardin Tropical in the south of Martinique is a clear case of a community where corals are recovering from perturbation. Macro-algal cover was high with 30% around 2010, but decreased strongly after to close to zero in 2013. Coral cover went down from 45 to 20 percent in 2010, but has now increased to approximately 30%. Turf algae appear relatively stable. The only significant trends are the corals and macro-algae.

Multivariate analysis

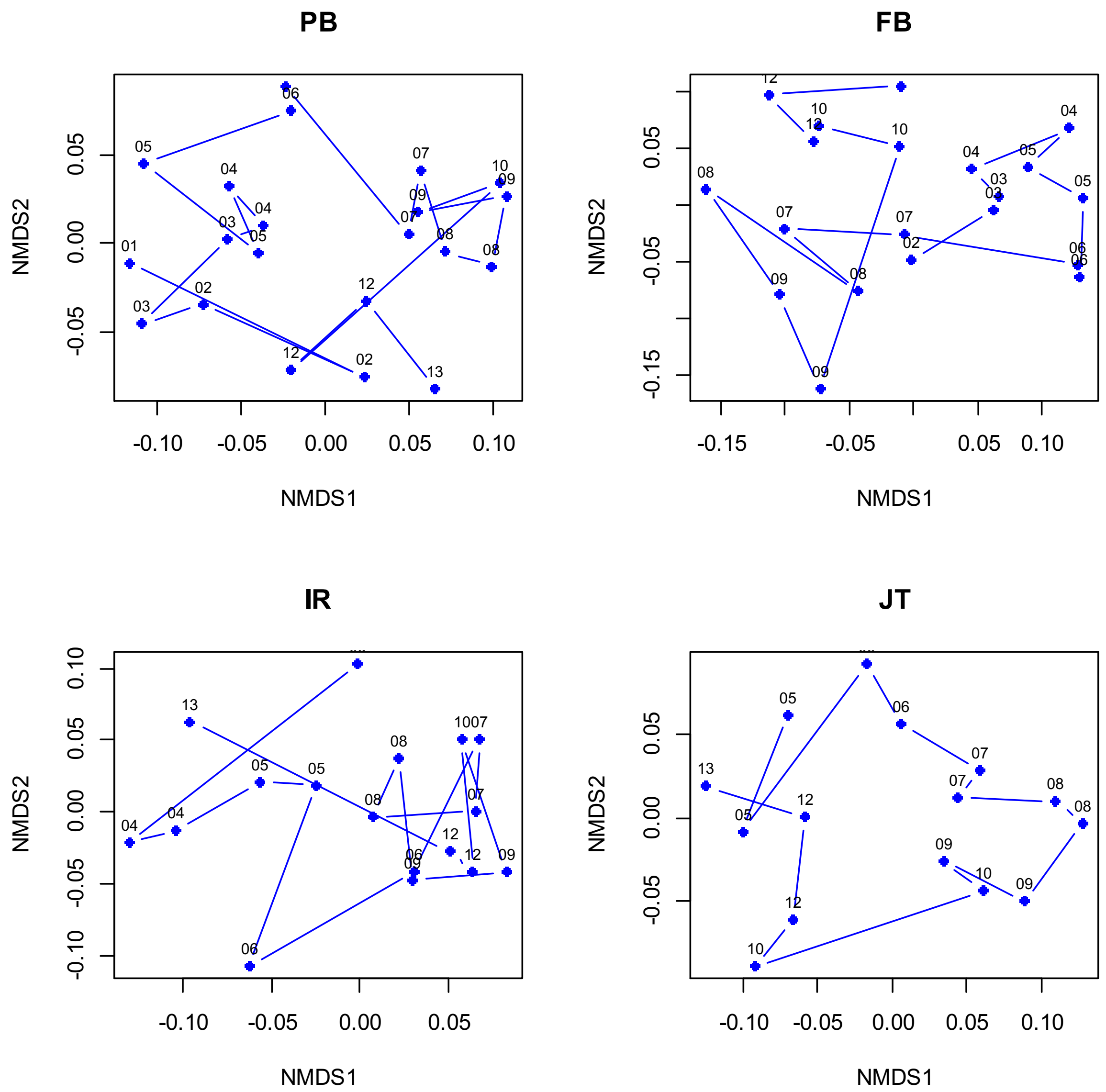


Figure 5. Multivariate analysis using non-metric Multi-Dimensional Scaling (nMDS). Each point depicts a community composition and the closer points are the more similar they are in composition. Numbers refer to the last two digits of the year. Abbreviations: PB, Pointe Borgnesse; FB, Fond Boucher; IR, Ilet à rats; JT, Jardin Tropical.

The community in Pointe Borgnesse (PB) develops slowly away from the initial composition as points increase in distance with time till about 2010. Then, there appears a little recovery as the points from 2012 onward move a little closer to 2001. This is however not the result of an increase in corals, but more due to a decrease in macro-algae and in 2013 the community is again far away from the situation in 2001. Between 2007 and 2010 there was a short period of stability with little change. Concluding Pointe Borgnesse appears to be gradually degrading in quality.

In Fond Boucher (FB) the community first moves away from its initial state (2004-2006) and then, from 2007 to 2009 it develops in a very different direction. In 2010 there appears to be some restoration to the baseline, but later it becomes more and more dissimilar from the early years when sponges increase in cover. The community changes not necessarily becoming more degraded, but definitely different with less coral cover.

At Ilet à rats (IR) the community appears quite stable from the end of 2006 till 2012, with most change occurring from 2003 to late 2006. In 2013 the community is much like in 2003. Relatively to the other sites Ilet à rats is the most stable site.

At Jardin Tropical (JT) the community first changes dramatically from 2005 to 2008, but then starts to recover. In 2013 it is very much similar to the situation at the start in 2005.

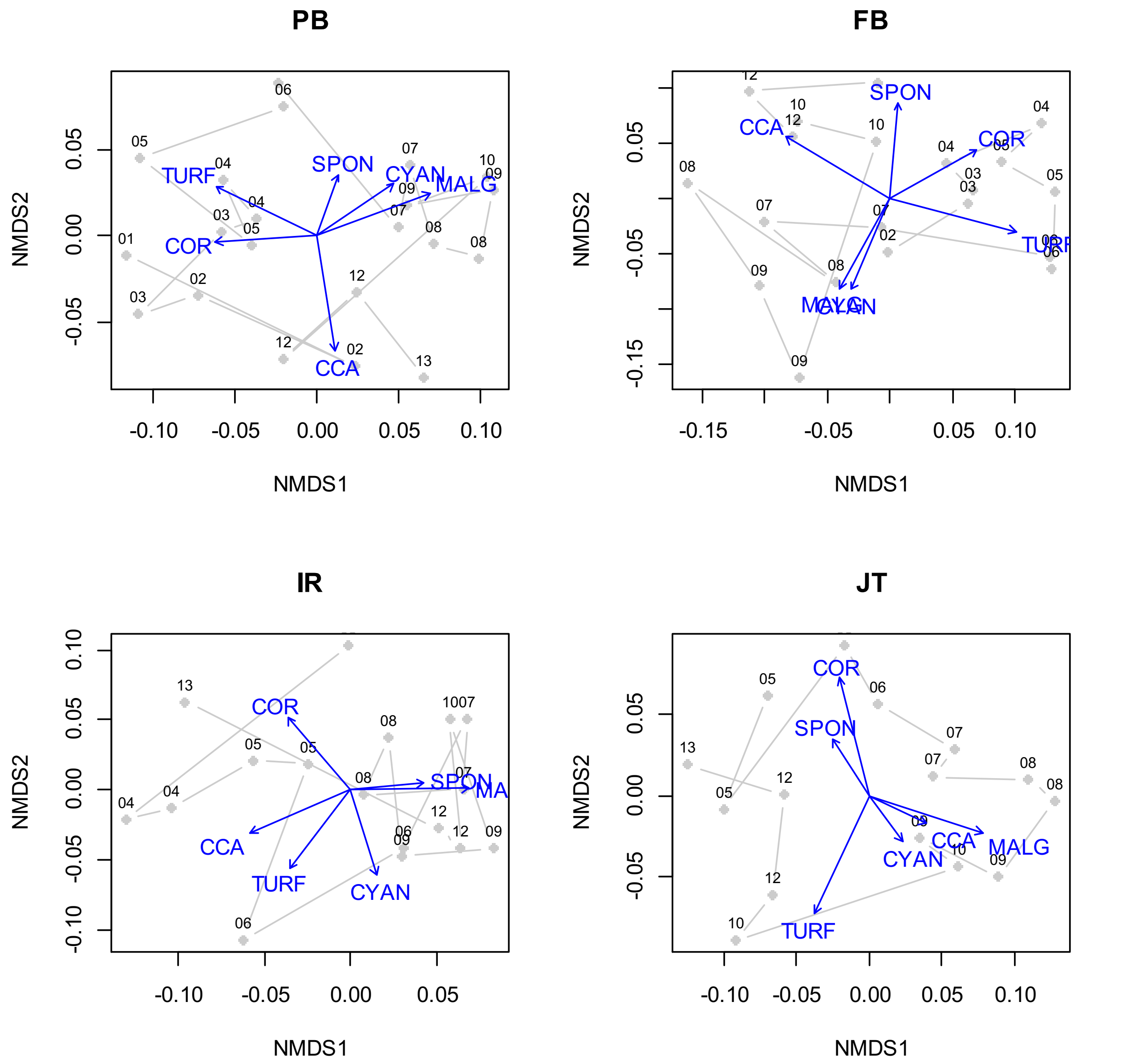


Figure 6. Multivariate analysis using non-metric Multi-Dimensional Scaling (nMDS) including arrows that depict the direction (and strength) of highest positive correlation with the 6 benthic categories. See Figure 5 for explanation of points and abbreviations.

Control charts

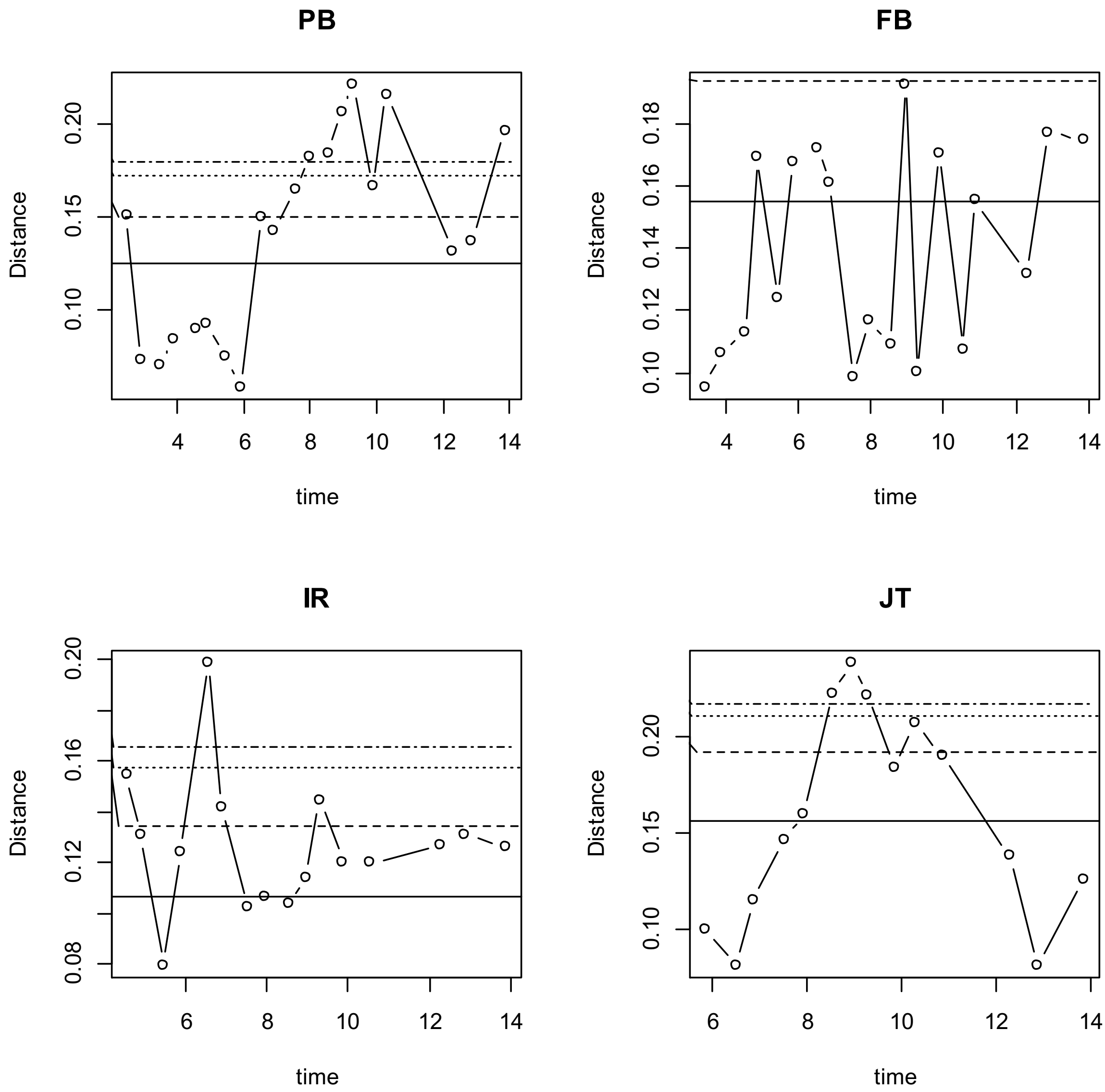


Figure 7. Multivariate control charts. Each point depicts the community composition at a certain time. Abbreviations: PB, Pointe Borgnesse; FB, Fond Boucher; IR, Ilet à rats; JT, Jardin Tropical. Horizontal lines indicate the 50, 75, 90, and 95 percentile values.

Control charts show the development of the community from a baseline, which here is the first monitoring survey. At each time the distance to the baseline is determined and through bootstrapping we estimate how unlikely such a new distance is from pure chance. The patterns in Figure 7 confirm the descriptions given above but they also show when communities become significantly different from the baseline. suggest that the 90 percentile is better in view of the precautionary principle. Better safe than sorry so to say. The four communities can be characterised into four patterns. PB is an example of degradation, changing from one state to another. FB is oscillating strongly, changing from good to bad and back multiple times (though not significantly). IR provides an example of a stable community with little change and JT is a community that first changes significantly, but is able to recover to the baseline situation.

2. Marine Protected Areas

2.1. Concept

The concept of "marine protected areas" (MPAs) appeared in the 70s, after the awareness of the international community on often-irreversible consequences of human activities on the marine environment. Coastal marine areas accommodate large numbers of species and essential habitats for their survival. However, these areas are subjected to increasing human pressures, which make them very vulnerable. Most marine resources are overexploited and sustainability of fisheries is seriously threatened (Castilla 2000; Murray et al. 1999). Given this general observation, the need to implement coastal protection plans through the creation of MPAs quickly emerged as an effective method to support the protection of the marine environment and associated resources.

MPA is defined as "any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999).

MPA objectives are multiple and can support ecological approaches (Agardy 2000; Geoffrey et al. 2004; Harmelin-Vivien et al. 2008; Jones et al. 2004), fisheries (Agardy 2000; Bohnsack 1998; Botsford et al. 1997; Geoffrey et al. 2004) and / or socio-economic (Agardy et al. 2003; Agardy 1994; Carter 2003; Jones 2006).

There are different types of MPAs with varying degrees of protection (Francour et al. 2001):

- Areas with all types of fishing prohibited (no take zones) = limited Management - theoretical protection,
- Areas with no authorized resource extraction (fully protected areas) = no management - total protection,
- Areas with regulated uses (marine reserve),
- Areas with limited resources extraction for all users (Marine Management Area) = optimal management - rational protection.

To characterize MPAs beyond their management options, the International Union for Conservation of Nature (IUCN) has defined protection categories from 1 to 6, corresponding to the protection goals (1: Fully protected to 6: management of human activities in a management objective, restoration and protection).

Category I	Protected area managed mainly for science or wilderness pro- tection (Strict Nature Reserve/Wilderness Area);
Category II	Protected area managed mainly for ecosystem protection and recreation (National Park);
Category III	Protected area managed mainly for conservation of specific na- tural features (Natural Monument);
Category IV	Protected area managed mainly for conservation through man- agement intervention (Habitat/Species

	Management Area);
Category V	Protected area managed mainly for landscape/seascape conser- vation and recreation (Protected Landscape/Seascape);
Category VI	Protected area managed mainly for the sustainable use of natu- ral ecosystems (Managed Resource Protected Area). (IUCN, 1994)

"Marine reserves" is the most common management scheme used for marine protected areas, which have a legal basis to restrict uses such as boating, diving and resource extractions both for professional or recreational fishing (tourism, recreational fishing, boating). No-take zones are created only to regulate mining activities. The notion of no-take zones, created by Fishers' community has evolved into a multifunctional concept of "marine management area" to adapt the growing exploitation of coastal marine environment.

In 2005, 5,127 marine protected areas were listed worldwide (Chaboud et al. 2011). According to (Pauly 2010), this global area has increased, but only cover 0.8% of the world ocean. Only 1/10th of that coverage would actually be effectively protected. In 2010, more than 700 marine protected areas were listed in the Latin America and Caribbean region, covering more than 300 000 km^2, representing 1.5% of coastal waters (Swartz et al. 2010). Only 0.1% of coastal waters are protected through fully protected status without any authorized activity. Marine reserves represent 0.3% of coastal waters. Some mining activities are allowed. Marine Management Areas are less represented, but cover 1.2% of the coastal waters.
Many actions are carried out to enhance protection and conservation of marine areas, both by improving the management of existing MPAs and developing new MPAs. These new areas are strategically located in order to increase connectivity and sustainability of the existing protection and develop new networks (Guarderas et al. 2008).

2.2. Marine reserve “effect”

The reserve effect is a notion covering all the positive and negative consequences of protective measures over a maritime area (Harborne et al. 2008; Seytre and Francour 2014; White et al. 2008). The reserve effect, from an ecological point of view, is the best-known phenomenon (ecosystem change, stocks restoration...). One of the most easily identifiable consequences is the increase of sensitive species populations (Harmelin-Vivien et al. 2008). This effect was shown primarily on populations of fish and crustaceans, like lobsters, because of their economic importance in coastal areas (Gallacher et al. 2016).
Many studies confirm that within protected areas, the number of target species for fisheries is higher, with densities and sizes values higher than in unprotected areas (Gell and Roberts 2003; Roberts 1998). Other aspects such as the economic impact of protection measures (effects on local fisheries, recreation and tourism, cost of implementation and management of MPAs...) or social impacts (reduction of conflicts between user groups, community

participation in management of the marine environment...) are often more difficult to detect (Wiber et al. 2004).
Conservation significantly reduces human impacts and creates a reserve effect more or less quickly. However negative effects can be highlighted correlated to increasing human use and increasing fishing pressure outside the border areas of the MPAs.

Three characteristics of MPAs' effects are discussed:
- Positive effects of MPAs
- Positive effects outside MPAs
- Negative consequences of conservation

2.2.1. Expected positive effects inside MPAs

The establishment of an MPA induces measurable benefits, especially in terms of conservation of the natural environment and resource management.

- Increased biodiversity

The protection of a marine area promotes biodiversity restoration, including the return of sensitive species. Species richness is often more important in protected area (Alcala and Russ 1998; Denny et al. 2004; Roberts and Polunin 1992; Russ and Alcala 2004; Russ et al. 2004). MPAs provide "sanctuary areas", encouraging conservation and restocking of adjacent marine areas, including the most threatened by intensive fishing or non-selective gears (Roberts 1995; Roberts et al. 2001).

- Food stands

Generally, the most common observation in overexploited areas is a reduced number of large sizes fish targeted by small-scale fisheries, and populations of smaller fishes than usual. Fishery bans inside MPAs increase the lifespan of individuals and, in the long term, restore the age and size structure of sensitive populations. For these populations, increases in average and maximum sizes are quickly observed within the protected area (Chiappone et al. 2000; Gerber et al. 2002; Jennings et al. 1995).

- Increase in total biomass

The abundance and size of individuals is directly correlated with conservation dynamic. The total biomass increases logically within the protected area (Bohnsack 1998).
Biomass increase has been measured in marine parks of Saba and Belize (Polunin and Roberts 1993). This study showed that after 4 years of protection, biomass increased by a factor of 2, including snappers (Lutjanidae) and grunts (Haemulidae) (Gell and Roberts 2003; Polunin and Roberts 1993).

- Increase in reproductive capabilities

Fecundity (egg production) of many fish species increases with age. Some species change sex during their maturity (female in the early stages of maturity and advanced male at adult stages). Improving reproductive potentials begins in protected areas, thanks to the increase in abundance of spawning adults, sex ratio balance and breeding and nursery areas. This increased reproductive potential is a major factor of the effectiveness of protected areas (Bohnsack 1998).

- Conservation of critical habitat

Fish populations and assemblages depend directly on habitat quality, including health status associated with biological communities. Habitat conservation efforts support better food webs and effectiveness of nurseries, as well as larval recruitment areas (Roberts and Hawkins 2000). Spawning sites during fish breeding are also protected from any harvesting when included in protected areas (Burton et al. 2005; Fontes et al. 2009).

2.2.2. Expected positive effects outside MPAs

Migration of fish outside MPAs is the main argument for the establishment of protected areas, particularly to get agreement from professional fishermen.

- Larvae, juvenile and adult exports

Many marine species, including fish, have non-sedentary phases during their life cycle. These phases can occur during larval development with planktonic eggs that disperse with currents. Larval dispersal will result in settlement sites often far away from the spawning sites. Larval recruitment and survival chances on harvested sites are more favoured where predation is lower (Daniel 2008; Vallès et al. 2009).

Beyond the planktonic phase, many species may experience migration phases as adults to reach spawning grounds and feeding areas, or as juveniles to re-colonize new habitats.

In 1996, a study conducted by (Russ et al. 2003) in Apo Island MPA in the Philippines highlighted the export effect through the study of large predators' densities (Serranidae, Epinephelinae, Lutjanidae, Lethrinidae and Carangidae) over a period of 10 years, inside and near the reserve. After eight years of protection, the density of these families had increased significantly in the 300 m zone around the protected area. This benefit in outside fishing grounds was correlated with sociological surveys of fishermen in the area. These investigations have shown that fishermen were unanimous on the fact that yields had increased since the reserve was established (Alcala and Russ 1998). One limitation of these findings is that spillover effect is observable over very small distances, which necessarily involves the establishment of MPA networks for management to be effective on large fishing areas (Russ and Alcala 2004).

The biomass export effect suggests possible migration of fish outside the protected area. The biomass transfer is carried out either by adults, juveniles or larvae, but it remains difficult to scientifically prove it (Ashworth and Ormond 2005; Rowley 1994).

2.2.3. The negative effects associated with MPAs

Overcrowding of MPAs through tourism activities and overexploitation at outside border areas by small-scale fisheries are two factors that may affect conservation measures. However, these effects seem outweighed by the benefits of protection associated with marine ecosystem restoration (Roberts et al. 2005).

- Increased fishing pressure on neighbouring areas

MPAs increase the fishing effort alongside the outside borders (Alcala and Russ 1998; Roberts et al. 2005). The attractiveness of MPAs and biomass export concepts are motivational criteria to increase fishing activities at the border location. This increased fishing activity, coupled with poaching, could limit or cancel the benefits (export of biomass) in neighbouring areas.

- Impact of overcrowding

MPAs can promote the development of tourism activities. Attendance zone may increase significantly. Water activities on the area increases and can cause severe mechanical damage to the environment (pleasure boat anchors on the bottom, the effect of divers or poaching of coral and seagrass by bathers) (Chabanet et al. 2005).

2.3. Performance criteria

Management of MPAs is critical to insure the effectiveness conservation measures. Criteria to optimize conservation in MPAs have been described.

2.3.1. Size of the MPA

The first parameters taken into account during the design of MPAs are location and surface area. A study by (Halpern and Warner 2003) on worldwide MPAs showed that MPAs, regardless of size, allow marine resources density, individual size and diversity to increase in all functional groups. On average, the increase in diversity and size of individuals is approximately 20% to 30%. Both density and biomass increase in protected areas.
(Roberts 1998) indicates that species and fisheries conservation is significant when protection zones encompass 20% of all fishery grounds of the territory. Small size MPAs can be effective if they are well managed and organised as a network. This network allows fishermen to directly benefit from fish surplus off the MPA.

2.3.2. Structure and habitat

Habitat protection does not affect significantly recruitment processes of juvenile fish. However, the specificity of juvenile's habitat for each species and nursery habitat areas, are the main factors to influence recruitment (Harmelin-Vivien et al. 1995). Nurseries are almost always located in shallow waters. Location of MPAs should consider these aspects to improve stock restoration and ensure success of the marine reserve (Francour et al. 2001).

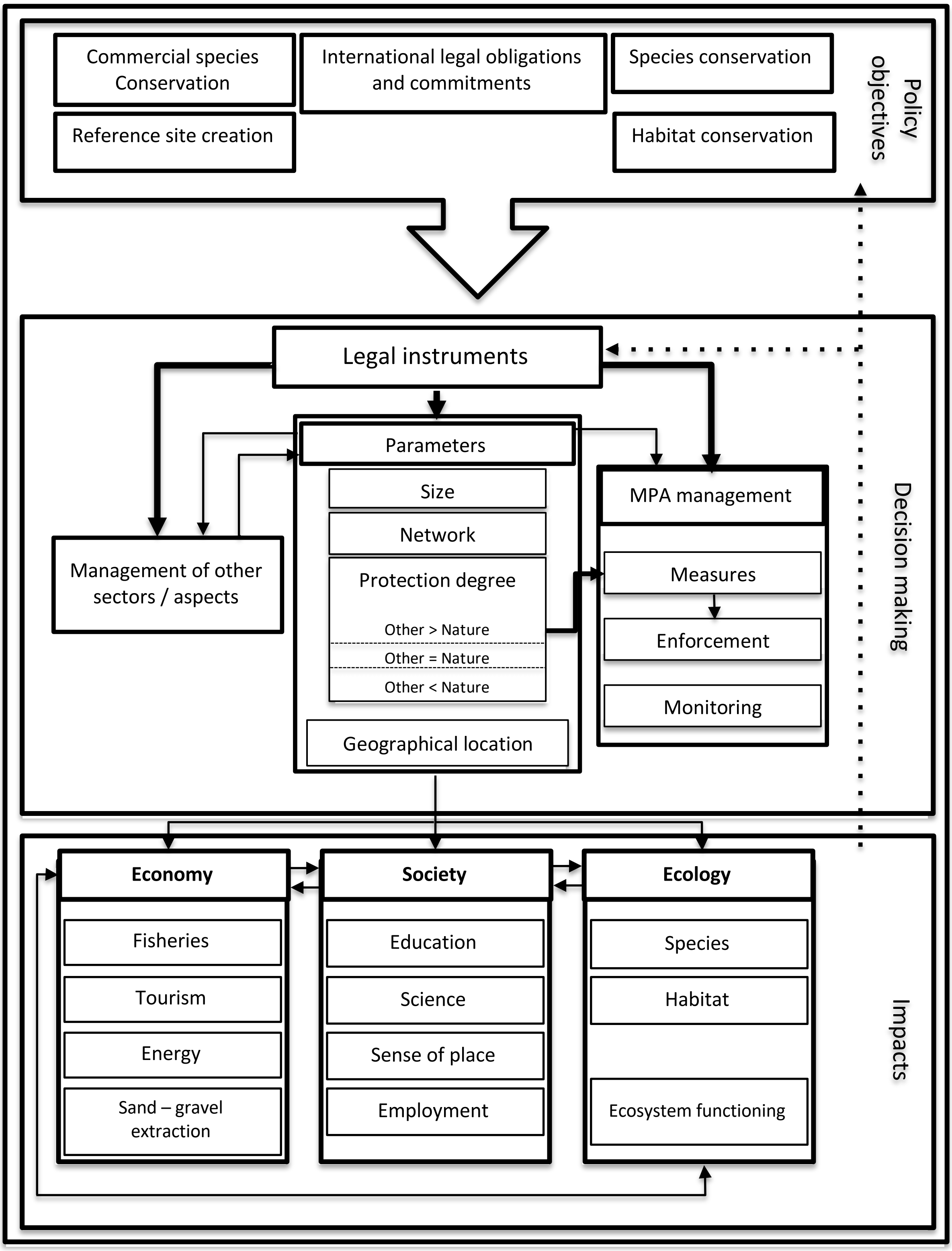
According to (Banks and Skilleter 2007), a minimum of 24% of critical fish habitats is necessary to achieve good efficiency of the MPA.

2.3.3. Minimum protection duration

(Halpern and Warner 2003) reviewed the performance of 80 MPAs worldwide. They concluded that protection over 1 to 3 years allowed to detect preliminary signs of reserve effects and that these effects were stable over time. Protection of fish species diversity depends more on MPA surveillance and durability of protected areas than size of the MPA. These two aspects directly influence stock restoration processes (Barrett et al. 2007; Koeck et al. 2015; Schill et al. 2015; Soria et al. 2014).

2.4. Conclusion

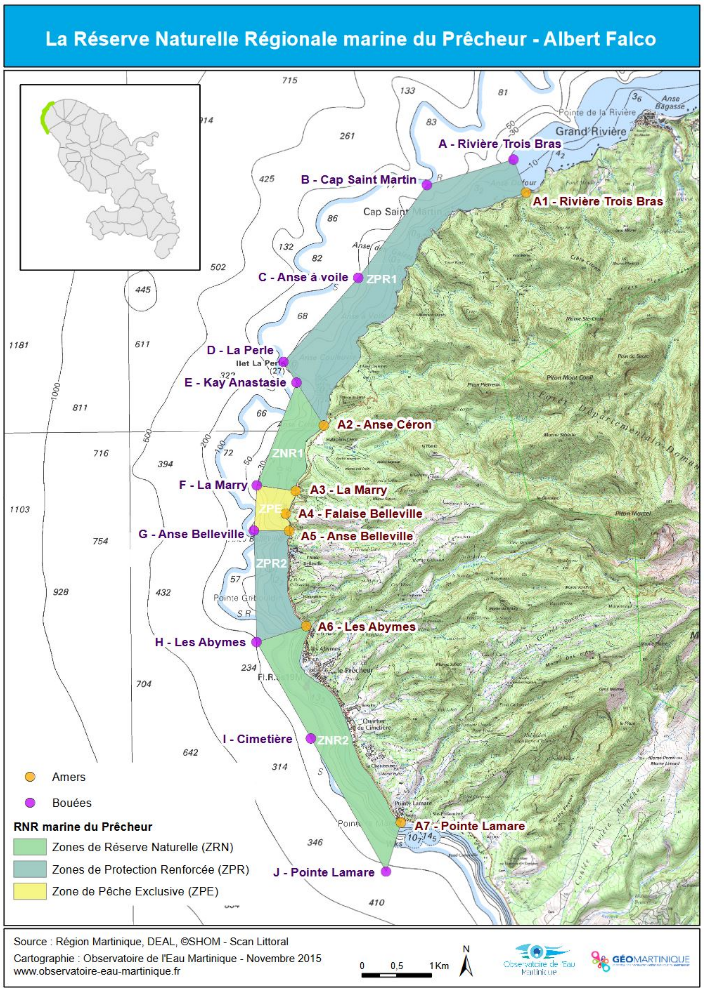
MPAs combine both resource conservation and economical benefits. In an ideal management model, conflicts of interest between those who exploit and those who wish to protect species are limited by regulation of uses and proper zoning taking into account the demands of the stakeholder groups and the specificities of professional and recreational activities (Roberts 1998). Most well managed MPAs provide substantial economic benefits to the regions concerned. However, career change is often suggested, including fishing, and is not always straightforward and easy to implement. Many cultural and social criteria have to be taken into consideration.



Flow chart as a visualization of the analytical systems approach. Three horizontal layers represent the 'MPA-process' over time. This approach starts with the identification of the policy objectives (five different objectives exist). The designation and management scheme are settled during the decision making phase, in which there is also consultation with the management of other sectors. Established MPAs are expected to have an impact on the socio-economic activities of the concerned area as well as on the ecology of the system. This systems approach helps to analyse and evaluate the 'MPA-process' in soft-bottom marine areas. After (Rabaut et al. 2009)

3. Case studies

3.1. Martinique: the Prêcheur Marine Protected Area (PMPA)



3.1.1. Ecological diagnostic

3.1.1.1. Ecological inventory

The MPA area was characterised along 9 sites of coral communities.

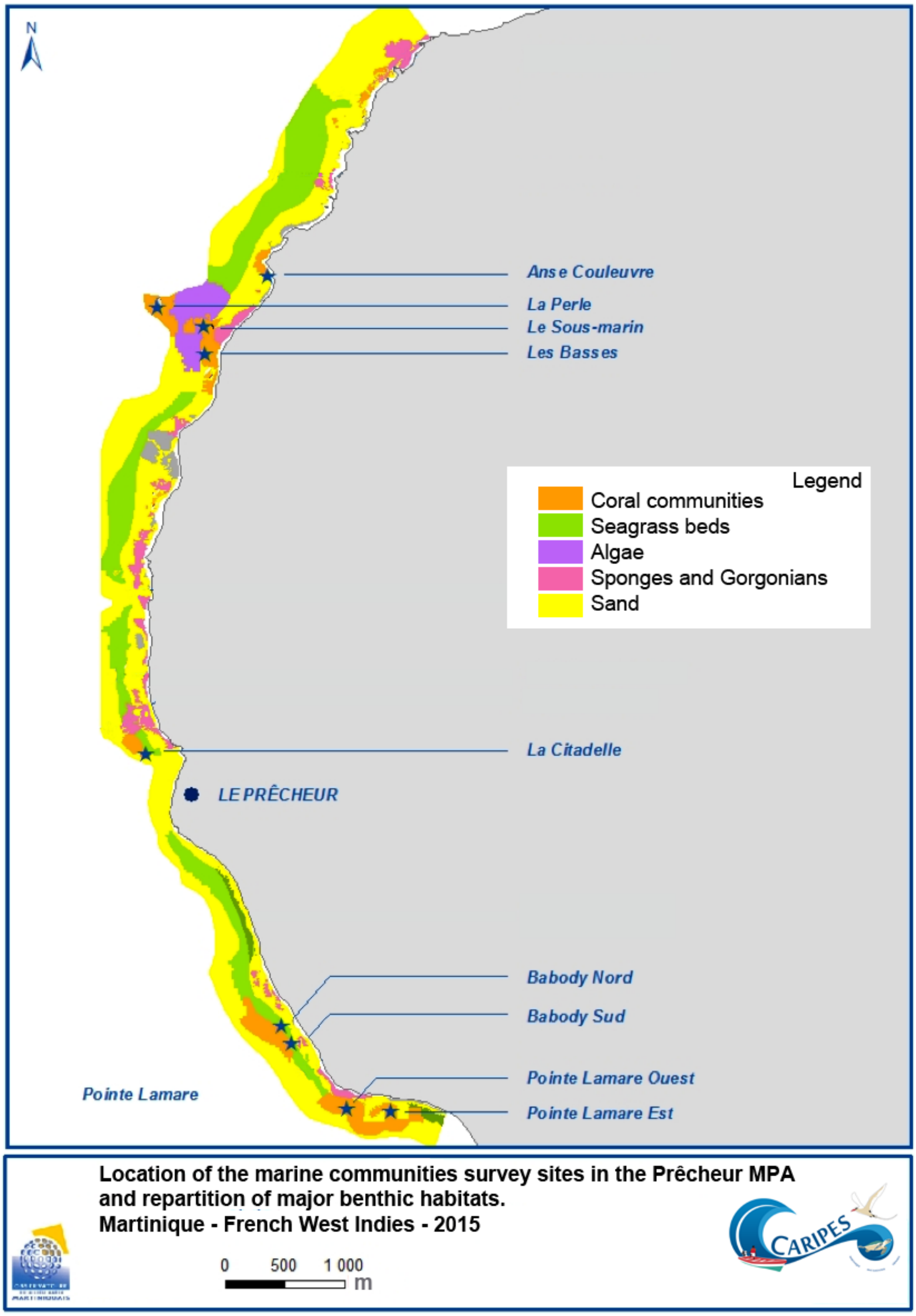


Figure 8. Mapping of the major marine habitats and location of the 10 sites surveyed in the Précheur MPA in Martinique.

Method

The water column depth 0-30m was examined with scuba diving methods, allowing an ecological characterization of habitats and ecosystems *in situ* according to the following framework:

1) Assess marine biodiversity from 30m deep to the surface.

2) Assess the coverage of benthic communities and associated fish assemblages in the highest biodiversity depth range (10-15 m).

3.1.1.2. Biodiversity inventories

Nine sites were sampled to characterize qualitatively the MPA area for 0 to 30 m depth (10 coral communities sites, 5 seagrass beds and 2 sandy area).

A biodiversity database for each of the surveyed sites has been elaborated as spreadsheet file, accompanied by a photographic base for each organisms identified (Taxonomy classification according to current schedule tables "Genus species", photo identification, depth, nature of the surrounding habitat, comments).

The dives were conducted down to the 30m depth limit, using depth intervals of 10m (30-20m, 20-10m, 10-0m) sampled during 20min. Additional night dives were programmed to complete the inventory, some species being visible at night only.

3.1.1.3. Quantitative evaluation of benthic cover and fish assemblages

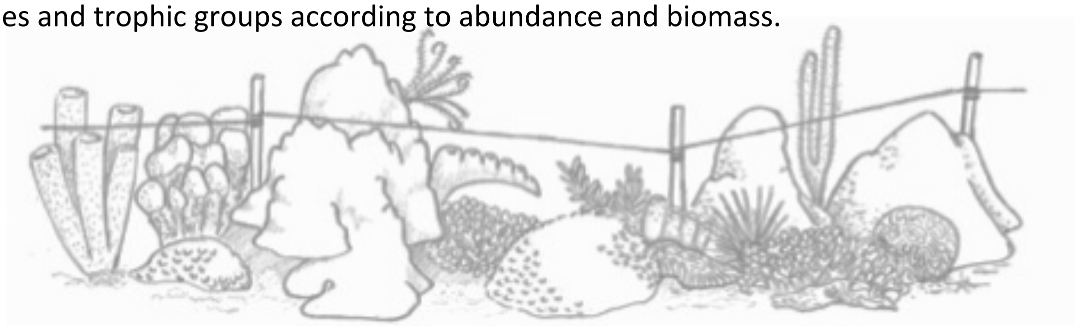
Quantitative surveys were conducted to assess the coverage of benthic organisms and associated fish populations.

Benthic cover

Three random transects of 50 m parallel to the coast and positioned on homogeneous ecological units were sampled at each site at a depth between 10 and 15m (highest marine biodiversity depth in Caribbean ecosystems). Photographs of transects were analyzed with the CPCE software. For each transect, 50 images were analysed using 20 random points. The species or the nature of the substratum at each point was recorded. Average cover per benthic groups is calculated to characterize the communities of each site of the prospect area.

Assessment of fish assemblages

On the same transects, fish species assemblages were assessed using visual census methods based on a list of target species for which abundance data (numbers) and size (size class) were recorded. During the first pass, mobile species are counted in a 4m belt transect (200m^2 sampled). In the second pass, local and cryptic species are considered in a 2m corridor (100m^2 sampled). Data is transferred into a spreadsheet and analyzed by species, families and trophic groups according to abundance and biomass.



3.1.2. Sites description

3.1.2.1. Site “Anse Couleuvre”

❖ *Benthic cover*

Weather conditions during the sampling campaign did not allow carrying out quantitative assessment of benthic coverage on that area.

❖ *Benthic species inventory*

The site is located at the bottom of a cliff and consists of complex rock habitats. It is very exposed to swell from the north Caribbean. Environmental conditions and rocky habitats are favorable to the development of corals, gorgonians and hydroids. Similarly with the previous site, it is not subjected to human activities.

110 animal species were identified, most of cnidarians and sponges typical of reef communities (Table 3).

Table 3. Species richness per groups and depth range - Site Anse Couleuvre

	Depth range	
	10-0m Volcanic rock substratum	Total number of species
Porifera	30	30
Cnidaria	47	47
Ctenophora	0	0
Platylminthes	0	0
Annelida	9	9
Bryozoa	1	1
Echinodermata	6	6
Arthropoda	10	10
Mollusca	5	5
Urochordata	2	2
TOTAL INVERTEBRATES	110	110
PHANEROGAMS	0	0
ALGAE	8	8
TOTAL PLANTS	8	8
TOTAL	118	118

Cnidarian biodiversity is dominated by corals as well as gorgonians, and specific hydroids. Thirty species of sponges were identified, representing 68% of the sponge species list of Martinique.

Remarkable species on this site:

Gorgonians	*Plexaura homomalla* *Eunicea mammosa* *Plexaurella sp.* *Gorgonia mariae*
Corals	*Isophylastrea rigida* *Dendrogyra cylindrus*
Hydroids	*Macrorhynchia clarkei*

❖ *Fish assemblage*

Due to the site configuration, only the 0-10m depth range was sampled.
Inventories related 39 species of fish belonging to 18 families: Pomacentridae and Labridae (6 species), Serranidae, Muraenidae and Lutjanidae (3 species), Haemulidae, Acanthuridae, Pomacanthidae, Holocentridae and Parrotfish (2 species). The other families are represented only by a single species such as: Cirrhitidae, Gerreidae, Ostraciidae, Carangidae, Monacanthidae, Tetraodontidae, Mullidae and Chaetodontidae.
Fourteen species are classified as "least concern" on the IUCN Red List. Large predators on this site were *Carangoides ruber*, *Ocyurus chrysurus*. Unusual species are also observed: Cantherhines pullus, Holacanthus tricolor and Pomacanthus paru.

3.1.2.2. Site "La Perle"

❖ *Benthic cover*

At 10m, cover reaches 35.1% for corals and 17.2% for sponges. Turf algae cover accounts for 24.5%. Macroalgae, mainly Dictyota species, represent 7.3% of the cover. Calcareous algae cover 8.6% of the bottom.
The bedrock of the eastern sector of La Perle is mainly colonized by *Millepora* (47.2%), but coral diversity is more important than on the west. Ten species were recorded, 6 species more than on the West sector. Except *P. astreoïdes* (15.1%), all species abundance was lower than 10%. Porites and Madracis (*M. mirabilis* and *M. decactis*) are pioneer species. *M. decactis* forms small fingered colonies. *M. mirabilis* forms short and dense clumps of branching colonies. The specimens are small (60 cm on average) and some massive corals were recorded (*Colpophyllia natans*, *Dendrogyra cylindrus*). An impressive colony of *D. cylindrus* is visible on site but only 20% of the colony persists. The site, at this depth, is in a relatively good condition.

At 20m, the site strongly resembles to the West sector in terms of benthic ecosystem, but the presence of large gorgonians (*I. schrammi*) is less clear. However, their presence on the drop-off area is important (Figure 2 and Figure 3).

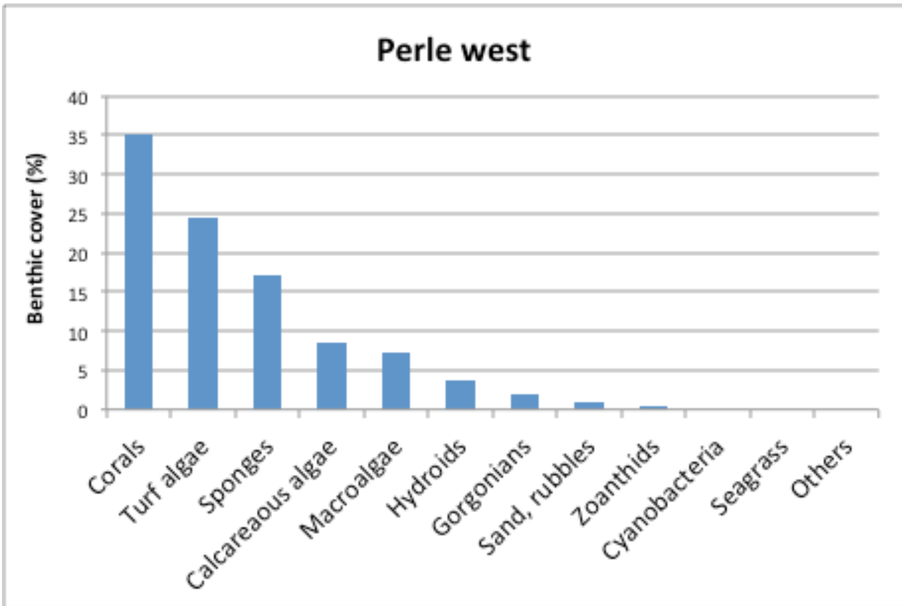


Figure 9. % benthic cover - Site La Perle west

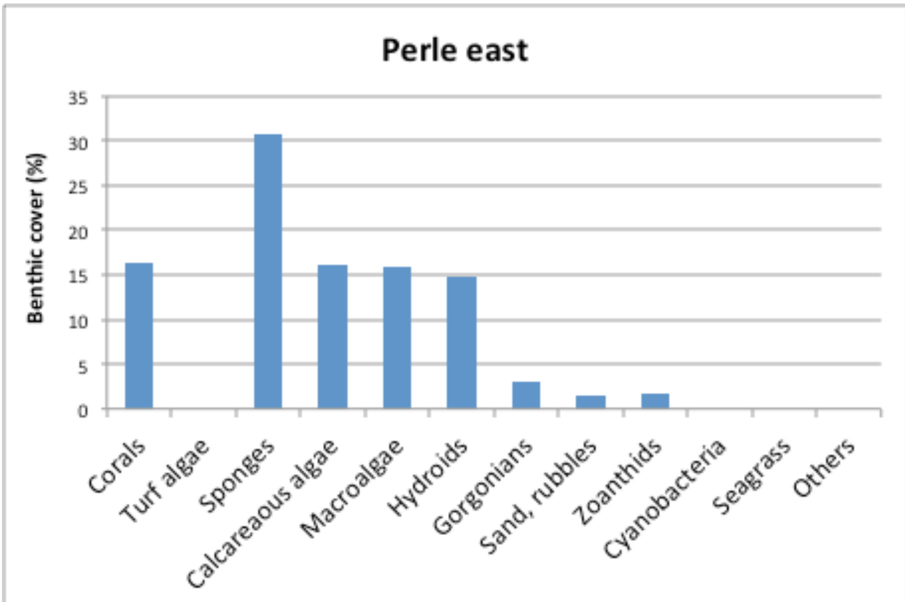


Figure 10. % benthic cover - Site La Perle east

❖ *Fish assemblage*

75 species of fish belonging to 29 families were sampled.
Families less represented are Haemulidae, Serranidae, Labridae (7 species), Pomacentridae and Holocentridae (6 species), parrotfish (5 species), Lutjanidae (4 species). Families Ostraciidae, Chaetodontidae and Carangidae are composed only of 3 species.
Twenty species are classified "least concern" on the IUCN Red List. *Haemulon striatum* (striped Grunt) is classified as "insufficient data".
Large predators are reported: *Carangoides ruber*, horse-eye jack, *Ocyurus chrysurus*, *Scomberomorus regalis*, *Elagatis bipinnulata*, *Sphyraena barracuda*. Uncommon and rare

species are also observed: *Cantherhines macroceros, Cantherhines pullus, Centropyge argi, Epinephelus guttatus, equetus punctatus Haemulon striatum, Holacanthus tricolor, Kyphosus saltatrix, Melichthys Niger, Pomacanthus appeared, Plectrypops retrospinis.*

Species richness / family / depth

• 0-10m: 37 species. The Holocentridae are represented by 5 species, while total Pomacentridae is 4 species. Labridae, Haemulidae and Scaridae comprise 3 species in each family.

• 10-20m: 47 species. The Serranidae are represented by 6 species. The Labridae, Haemulidae, Pomacentridae and Scaridae account 4 species.

• 20-30m: 60 species. The Labridae and Haemulidae include 7 species. In this area, Pomacentridae and Scaridae gather 5 species. Four species for each Serranidae, Holocentridae and Lutjanidae.

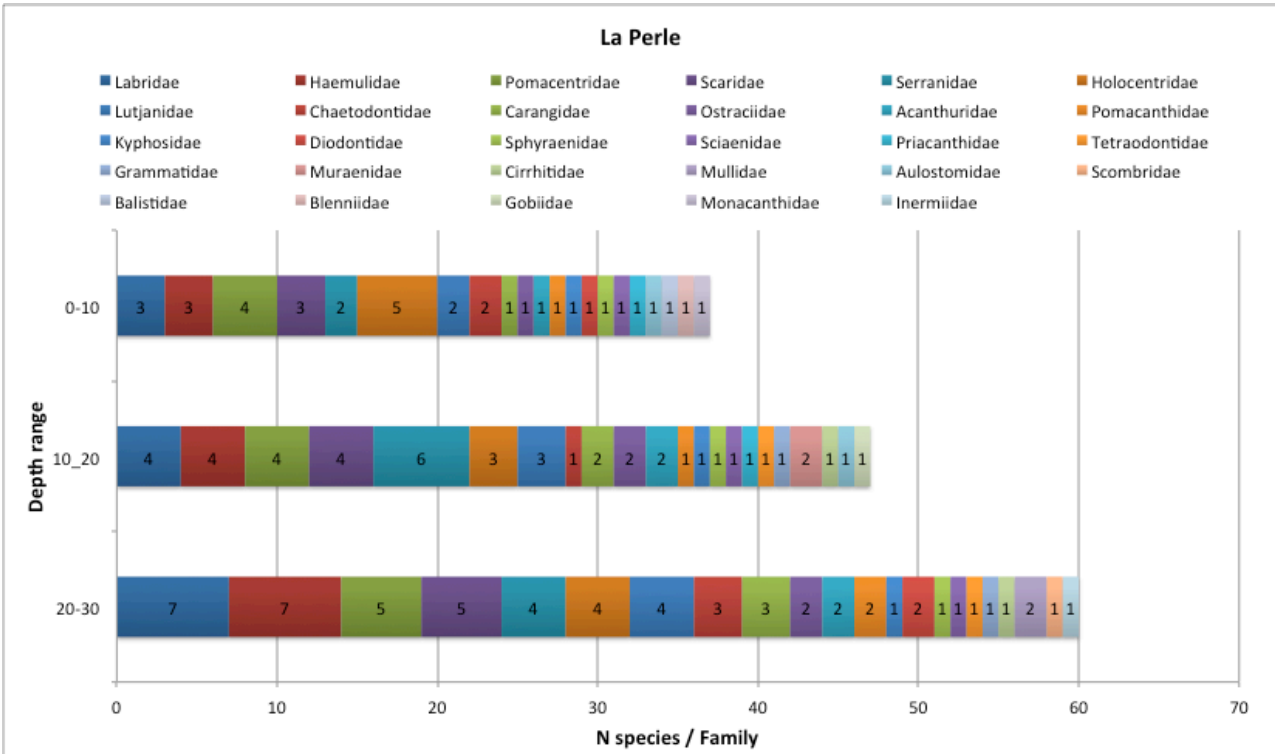


Figure 11. Fish species richness per family and depth range - La Perle

3.1.2.3. Site “Le Sous-marin”

❖ *Benthic cover*

At 10m depth, this site has a higher coral diversity than “La Perle”. *P. astreoïdes* is a relatively abundant species in this area. However, coral cover (28.7%) is slightly lower than that measured at “La Perle West” (35.1%). Turf algae represents a significant cover on this

site (38%). Sponges coverage is 11.3%. Calcareous algae and macroalgae are underrepresented. Sandy areas represent 13.3% of the sea bottom.
Colonies of Montastraea (*M. faveolata* and *M. cavernosa* = Orbicella) were sampled. *Millepora* occurrence is reduced (2.3%) compared to “La Perle”. The habitat complexity of the site promotes species diversity. The coral population is more homogeneous than “La Perle” sector. However, only four species account for 67.5%: *C. natans*, *M. meandrites*, *M. cavernosa* and *P. astreoides* (Figure 5).

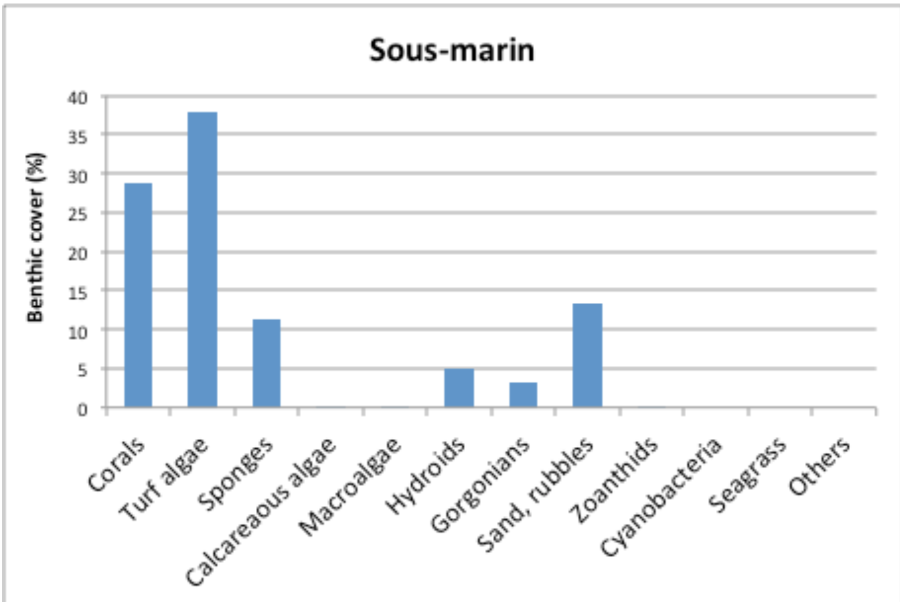


Figure 12. % benthic cover - Site Le Sous-marin.

❖ *Fish assemblage*

✓ Species richness

84 species of fish were recorded.
Families with the lowest number of species are Labridae (8 species), Haemulidae (7 species), Pomacentridae, Scaridae, Serranidae (6 species), Carangidae (4 species). Acanthuridae, Chaetodontidae, Pomacanthidae and Holocentridae have 3 species each.
25 species are classified as "least concern" on the IUCN Red List.
Large predators are reported: *Carangoides ruber, Caranx crysos*, horse-eye jack, *Ocyurus chrysurus, Scomberomorus regalis, Sphyraena barracuda*. Rare species were also observed: *Anisotremus surinamensis, Cantherhines macroceros, Cantherhines pullus, Centropyge argi, Epinephelus adscensionis, Epinephelus guttatus, Equetus punctatus, Holacanthus tricolor, Kyphosus saltatrix, Pareques acuminatus, Pomacanthus paru, Monacanthus tuckeri.*

✓ Density and biomass / Family

Fish density value is of 1033 ± 307 ind/200m² repsenting 20 families. The Pomacentridae account for 78% of total abundance.

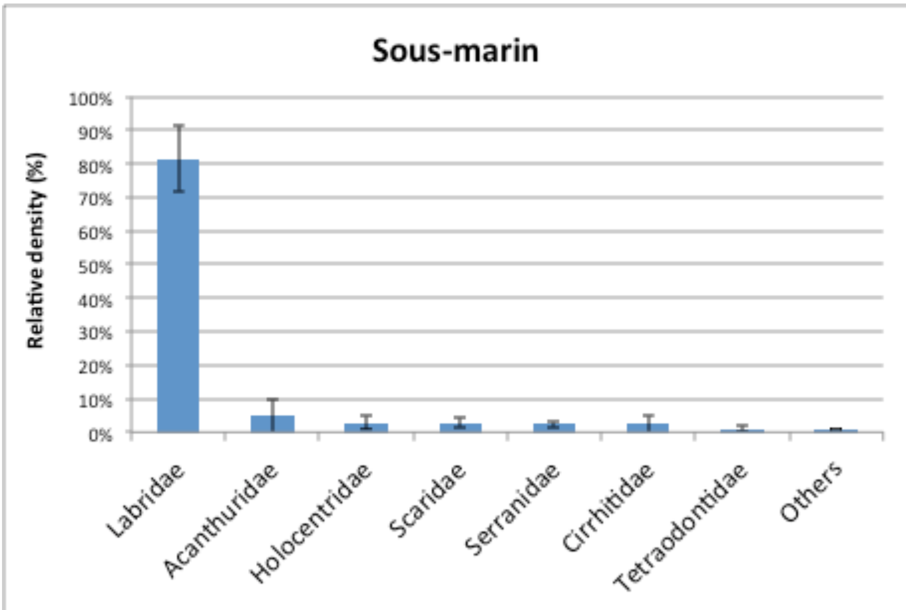


Figure 13. Average density of major fish families (± std error – families under 1% not represented - Pomacentridae not represented) - Le Sous-marin.

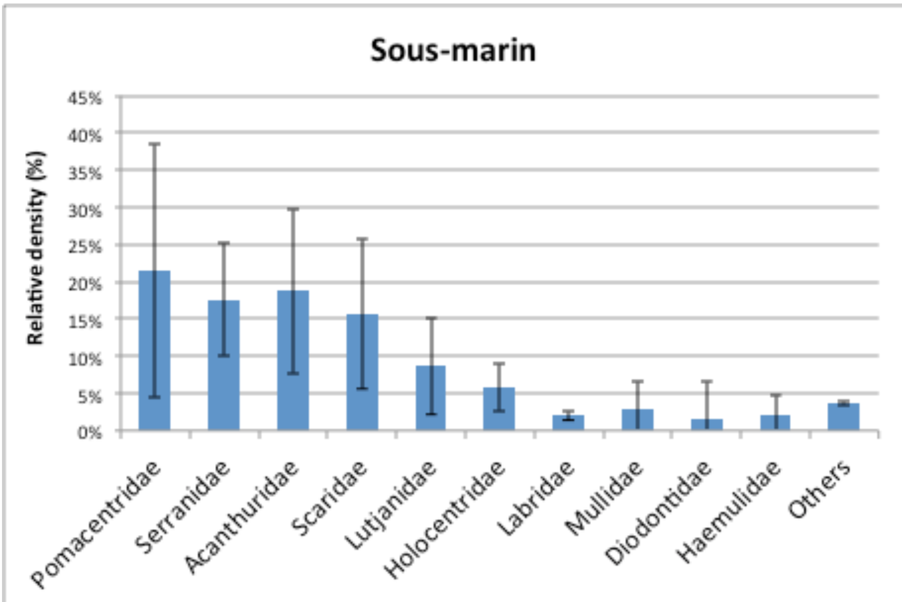


Figure 14. Average biomass of major fish families (± std error – families under 1% not represented) - Le Sous-marin.

The Labridae dominates the fish populations with an average proportion of 81 ± 10% (*Thalassoma bifasciatum* being the major species). Acanthuridae account for 5 ± 5% of the total abundance, while Holocentridae and Scaridae reach 3% each. Serranidae and Cirrhitidae contribute to 5%.

The average biomass is 5392 ± 2714g/200m². Ten families contribute to more than half the total biomass, including three major families: Pomacentridae (21 ± 17%), Serranidae (18 ± 8%), Acanthuridae (19 ± 11%). 16% of the biomass is composed of Scaridae, 9 ± 7% Lutjanidae, 6 ± 3% Holocentridae. The Labridae (2 ± 1%), Mullidae (3 ± 4%), the Diodontidae (2 ± 5%) and Haemulidae (2 ± 3%) are less represented.
The commercial species *Cephalopholis fulva* contributes for 10 ± 5% of the total biomass. *Acanthurus bahianus* and *Ocyurus chrysurus* account for 14% of the total biomass. The

biomass values for the different families have high standard errors showing a great inequality of the fish assemblages.

- ✓ Trophic groups

Trophic groups are represented principally by plantktotrophic fish (44%) and territorial herbivorous fish (47%). Despite these high values, territorial herbivorous marginally contribute to the total biomass (10%), 7% for planktivorous. Other herbivores constitute 34% of the biomass, but only 2% of the total abundance. Carnivorous contribute to 26% of the biomass and less than 1% of abundance. Consumers of mobile invertebrates contribute up to 10% of the biomass. Omnivores account for 11% of the biomass but only 1% of the abundance (Figure 8).

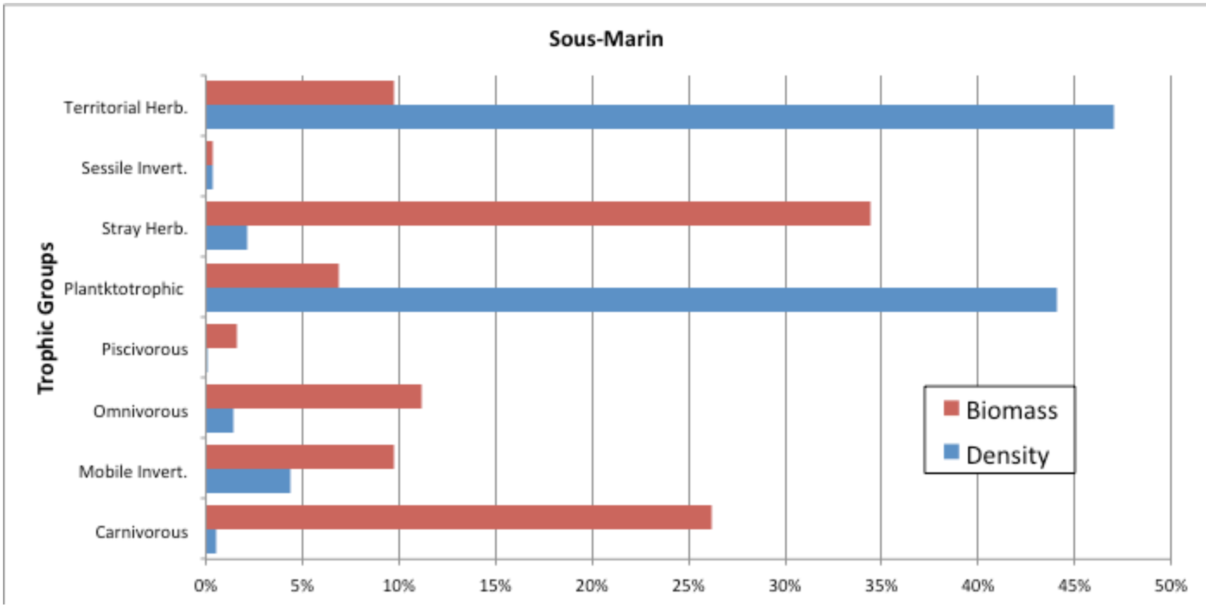


Figure 15. Abundance and Biomass per fish trophic groups. Le Sous-marin.

3.1.2.4. Les Basses

- ❖ *Benthic cover*

Depth 30-20 m

The sandy bottoms show many signs of invertebrates. Some solid substratums are covered with sponges (Aplysina) and coral colonies of small size. The rocky sustrate ends around 25m deep and sea bottom continues with a sandy area silted steep. Among the major sponge species encountered, Xestosponiga muta, Agelas conifera and Siphonodictyon coralliphagum predominate. Sea fans are present, both on hard and soft substrates. The main coral species observed are *Montastraea cavernosa*, *Meandrina meandrites* and *Siderastrea Siderea*.

Depth 20-10 m

Between 20 and 10m, a vertical wall covered with large *Agaricia sp.* colonies shapes the landscape. The communities are composed mainly of sponges and corals. A large area of

Madracis mirabilis is observed around 15m. *Dictyota sp.* are observed but at low-density levels. Corals present on the wall are *P. Porites*, *M. decactis*, *M. meandrites*, *M. cavernosa* and *S. Siderea*. Some gorgonians are observed. *X. muta* of impressive sizes cover the top of the rocks around 12-13m.

Depth 10-0 m

The top of the wall is at 10m deep. The landscape is globally flat but the sandy area is interspersed with grooves on which biological communities develop. At this depth, *Gorgonia ventalina* is an abundant species. The hard substratum is covered by M. mirabilis (+++), M. meandrites, *P. astreoides* (++), *M. alcicornis*, *S. radians* and *S. Siderea*, *E. fastigiata*, and P . *porites*. Some large colonies of *C. natans* are listed. The rocks are covered with annelids tube worms (+++). Sponges are less abundant than other depths. The rocks are covered with turf algae and macroalgae. Obvious signs of pollution are characterized by the abundance of cyanobacteria.

At 5m, the bottom is sandy and muddy. The hard substrate is silted and some gorgonians grow. Benthic cover from transect surveys reveals a significant presence of macroalgae and algal turf (39%). The coral cover varies given the nature of the substrate. However, coral cover represents 21.7% of the bottom. Sponges account for 15% of the benthic community. Other biological categories less than 5% coverage are not considered in the characterization of the community (Figure 9).

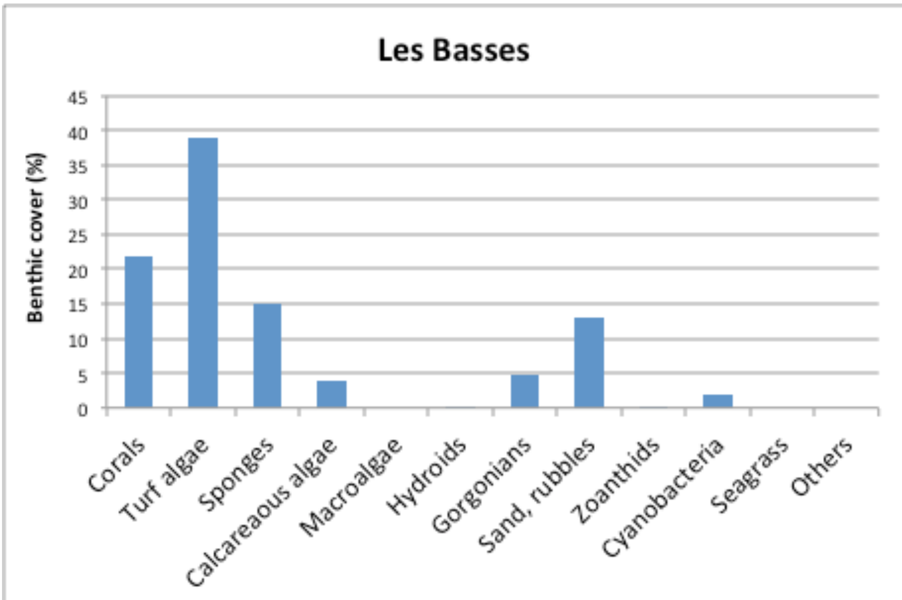


Figure 16. Benthic cover of major groups and substratum – Les Basses.

- *Benthic species inventory*

The site is a succession of sandy area (30 m deep) to a wall and spur and grooves between 25 to 5 m. The geomorphology of the site offers many habitats. The environmental conditions are favorable to the development of corals, gorgonians, hydroids and other groups. Many coral species indicates a historically stable environment. Several species considered rare or occasional on the Caribbean coast are observed. Human activities are almost non-existant on this site.

163 species, mostly cnidarians and sponges, are characteristic of a healthy and stable environment (Table 4).

Cnidarians are predominant species, as well as gorgonians and specific hydroids. They characterize an environment subjected to swell in the shallow reefs. An important sponges biodiversity (32 species) are described, corresponding to 73% of the species identified in Martinique. Habitat diversity and stability are in favour of the development of rare species on the Caribbean coast.

Table 4 Species richness per groups and depth range - Site Les Basses

	Depth range			
	30-20m Sand	20-10m Volcanic rock substratum	10-0m Volcanic rock substratum	Total number of species
Porifera	0	31	27	32
Cnidaria	1	58	61	74
Ctenophora	0	0	0	0
Platylminthes	0	0	0	0
Annelida	0	7	13	13
Bryozoa	0	3	1	3
Echinodermata	1	7	7	10
Arthropoda	0	12	11	18
Mollusca	2	4	8	11
Urochordata	0	2	2	2
TOTAL INVERTEBRATES	4	124	130	163
PHANEROGAMS	0	0	0	0
ALGAE	0	3	8	8
TOTAL PLANTS	0	3	8	8
TOTAL	4	127	138	171

Remarkable species:

Gorgonians	*Millepora complanata* *Plexaura homomalla* *Plexaurella sp.* *Plexaurella nutans* *Gorgonia mariae*
Corals	*Acropora palmata* *Madracis formosa* *Dendrogyra cylindrus*
Antipatharia	*Antipathes lenta*
Zoanthids	*Isaurus tuberculatus*
Bryozoans	*Bugula minima*
Echinoderms	*Astropyga magnifica*

❖ *Fish assemblage*

Species richness

84 species of fish belonging to 33 families: Serranidae (9 species), Pomacentridae and Haemulidae (7 species), parrotfish, Labridae and Lutjanidae (6 species), and Holocentridae Chaetodontidae (4 species).
Twenty-four species are classified as "least concern" on the IUCN Red List. Two are classified as "vulnerable": *Lutjanus analis* and *Mycteroperca interstitialis* (Virgin yellow mouth).

Large predators are reported: *Ocyurus chrysurus*, *Scomberomorus regalis*, *Sphyraena barracuda*. Rare species were also observed: *Anisotremus virginicus*, *Calamus calamus*, *Cantherhines pullus*, *Carangoides ruber*, *Equetus punctatus*, *Haemulon macrostomum*, *Holacanthus ciliaris*, *Holacanthus tricolor*, *Kyphosus saltatrix*, *Lutjanus analis*, *Pomacanthus paru*, *Mycteroperca interstitialis*.

Species richness / family / depth

• **0-10m:** 68 species. Scaridae, Pomacentridae and Labridae gather 6 species, while Serranidae, and Haemulidae account 5 species.
• **10-20m:** 52 species. Serranidae are best represented (7 species), followed by Scaridae and Pomacentridae with 5 species. Labridae include 4 species.
• **20-30m:** 46 species. Haemulidae, Serranidae and Lutjanidae are represented by 5 species each. Four species have been recorded for the Pomacentridae.

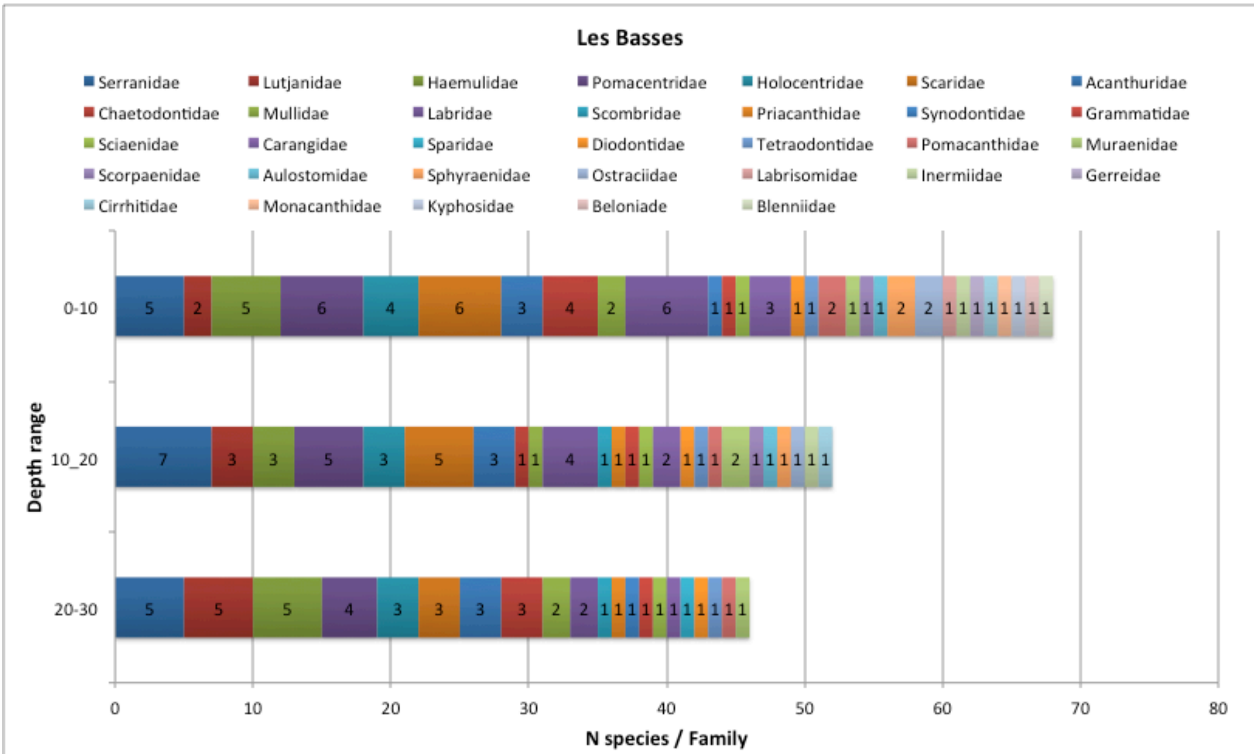


Figure 17. Fish species richness per family and depth range – Les Basses.

✓ Density and biomass / Family

Abundance value is of 601 ± 114 ind / 200m² for 17 families.

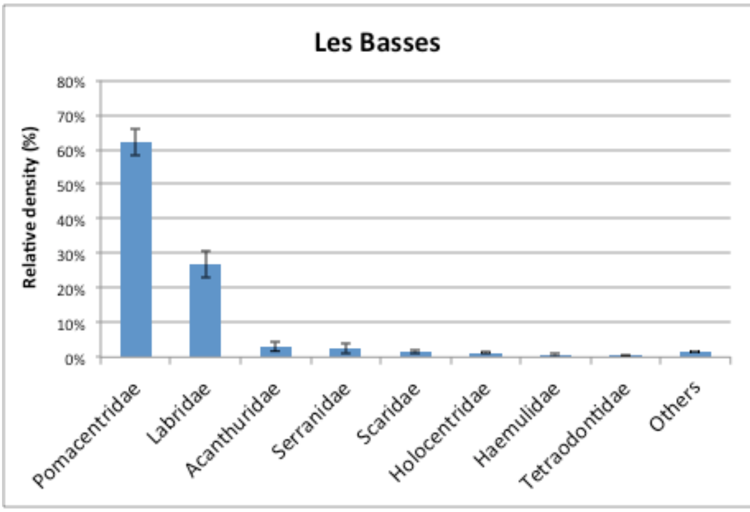


Figure 18. Average density of major fish families (± std error – families under 1% not represented) – Les Basses.

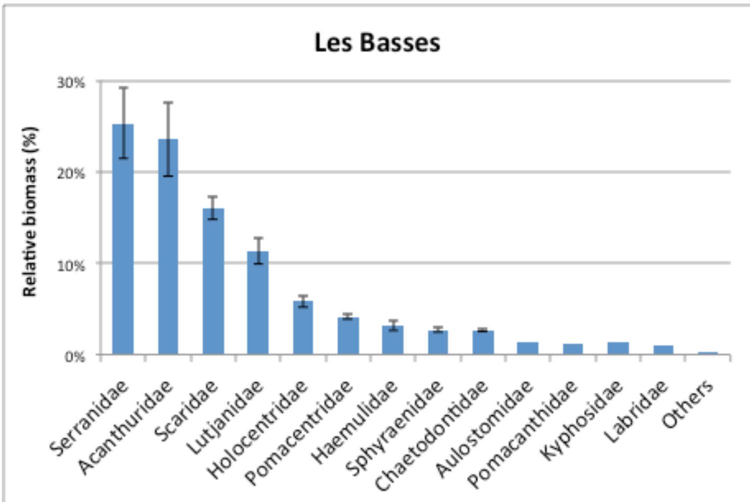


Figure 19. Average biomass of major fish families (± std error – families under 1% not represented) – Les Basses.

Pomacentridae dominate with an average of 62 ± 4% of the total abundance, *Stegastes partitus* being the major species. Labridae account for 27 ± 4% of the total abundance, second contribution to the assemblage (*Thalassoma bifasciatum* being the main species). Acanthuridae and Serranidae each account for 3% of total abundance against 2% for Parrotfish and 1% for Holocentridae, Haemulidae and Tetraodontidae.

The average biomass is 5357 ± 675 g / 200m². Thirteen families compose the total biomass. Among them, Serranidae (25 ± 3%), Acanthuridae (24 ± 12%), the parrotfish (16 ± 7%), contribute to more than half the total biomass. Lutjanidae participate in 11 ± 17% of the biomass, Holocentridae (6 ± 7%), Pomacentridae (4 ± 1%), and Haemulidae (3 ± 2%). Four species only represent half of the total biomass. Among them, we find *Cephalopholis fulva* (22 ± 3%), *Acanthurus coeruleus* (11 ± 9%), *Lutjanus mahogoni* (10 ± 18%), *Sparisoma* *aurofrenatum* (9 ± 2%). These species have a high commercial value. The biomass values for the different families have high standard errors showing a great inequality of the fish assemblages.

✓ Trophic groups

The total abundance consists of territorial herbivorous (56%) of planktonivorous (34%) fish. Despite these high values, territorial herbivores and planktonivores account only for 4 and 8% of the total biomass. Stray Herbivores only contribute to 5% of the total density but they account for 41% of total biomass. Carnivores represent 34% of the biomass but only 2% of total abundance (Figure 13).

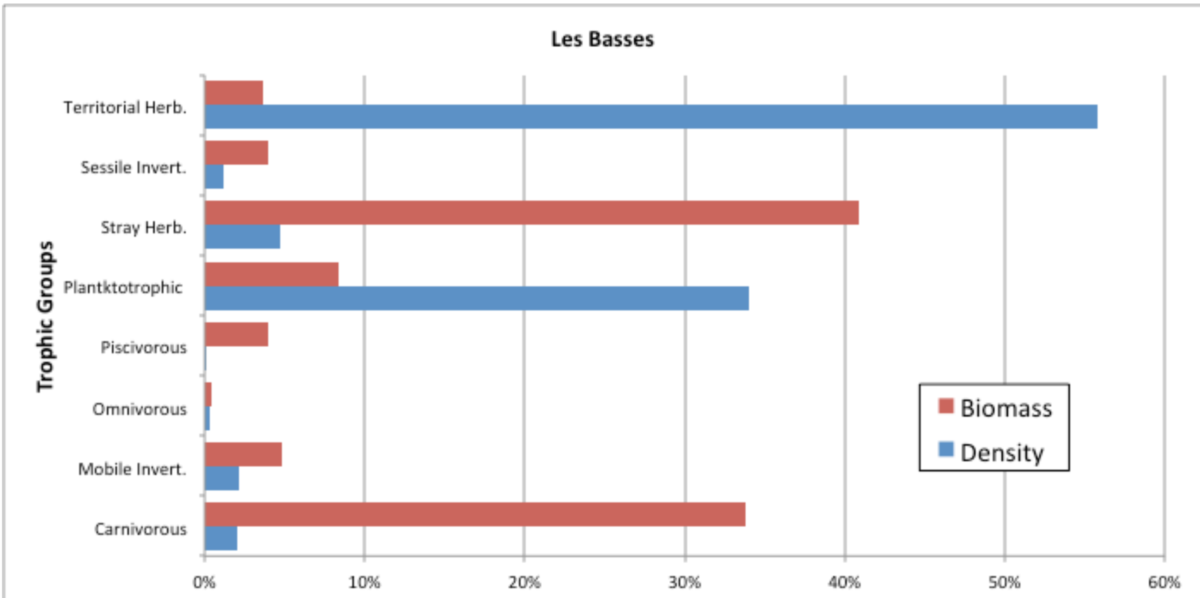


Figure 20. Fish density and biomass per trophic groups – Les Basses

3.1.2.5. La Citadelle

❖ *Benthic cover*

Depth 30-20 m

The deep zone is characterized by a vertical wall covered with Anthipatarians and other species, including sea fans and sponges like *S. vesparium*, *A. conifera*, *I. birotulata*, *X. muta* and *C. natans*. These walls also favour small size colonies of *Agaricia* species. At the bottom of the wall we find a sandy-muddy slope down to the depths. The base of the wall is characterized by numerous sponges: *X. muta*, *C. vaginalis*, *A. conifera*, *I. birotulata*, *A. fistularis*, *N. digitalis*. The walls are covered with dense populations of hydroids.

At the top of the wall, we find a sandy zone with patch reefs where are present large sponges *X. muta*, *E. ferox* (++) and *I. birotulata*. Beside the sponge populations are sea fans and hydroids (++). The coral colonies are small and the population is mainly composed of *Agaricia sp.*, *M meandrites*, *S. Siderea*, *M. decactis*, *C. natans* and *E. fastigiata*.

The health status assessed on the basis of benthic community composition, coral necrosis and siltation is estimated at 2/3 on a scale of 4.

Depth 20-10 m

This depth corresponds to the top of the drop, characterized by a sandy slope and boulders covered with hydroids. Between these blocks are present gorgonians of *Plexaurella sp.*. Hard substrates are covered with silted Turf algae (+++). Among the most common sponges we find *N. digitalis*, *A conifera*, *X. muta and Cliona sp.*. Major coral species are *M. mirabilis*, *Agaricia sp.*, *M. cavernosa*, *C. natans*, *S. Siderea* and *M. meandrites*.

Depth 10-0 m

The shallow area is composed of rock blocks and large sandy and rubbles areas. Populations of sea fans are very important.

Around 10-15 m depth, the communities are characterized by a high proportion of macroalgae and algal turf (48.4%). The site is exposed to strong currents, which promotes the development of sponges (18.6%). Corals represent only 13.9% of the community. The top of the reef drop-off at Citadelle is a sandy flat area with rock boulders. The coral colonies and other fixed benthic species develop mainly over these hard substrates. Sand and debris account for 14.9%, reflecting the site structure. Algae also develop secondarily on the sandy substrate which actually represents a larger part of the sea bottom in this area. Other marine organisms represent less than 5% of the communities are not included in this description (Figure 14).

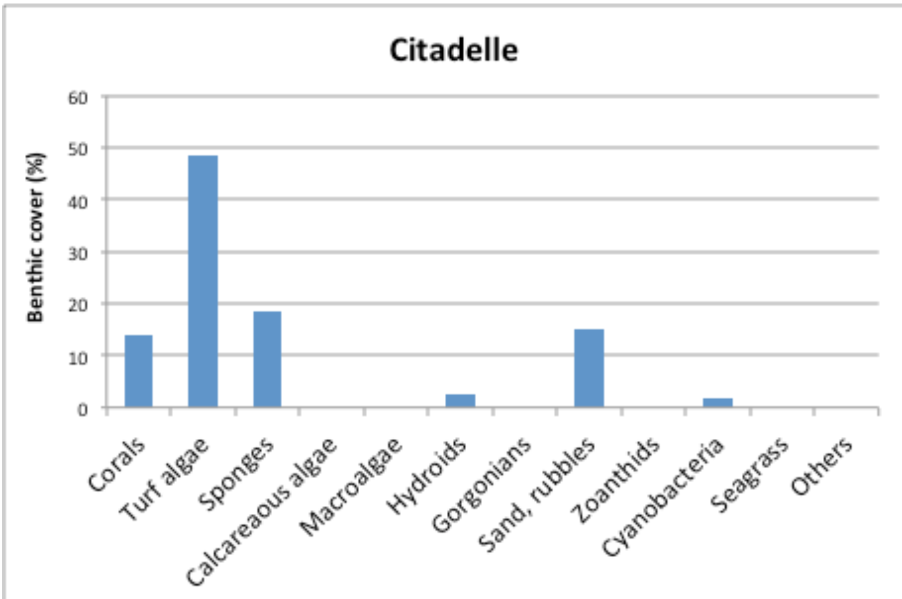


Figure 21. Benthic cover of major groups and substratum – La Citadelle.

❖ *Benthic species inventory*

The site successively froms a 30m drop-off, a “staircase” area and a flat sandy platform with sea fans. The deep and average areas are subjected to currents. The flat area is exposed to swell. These conditions are favorable to the development of corals, gorgonians, hydroids and other groups. The range of ecosystems supports a significant species diversity. The site is however regularly exposed to sediment supply from the river located in 'Le Prêcheur". This site gathers a large diversity of gorgonians, hydroids and antipatharian as well as many unusual species.

173 animal species were recorded, mainly cnidarians and sponges (Table 5).

Table 5. Species richness per groups and depth range - Site La Citadelle

	Depth range			
	30-20m Drop-off	20-10m Volcanic rocks	10-0m Patchy rock boulders	Total number of species
Porifera	32	33	31	37
Cnidaria	39	59	56	76
Ctenophora	0	0	0	0
Platylminthes	0	0	0	0
Annelida	10	15	12	15
Bryozoa	2	2	1	2
Echinodermata	6	8	6	13
Arthropoda	7	12	15	17
Mollusca	4	6	5	9
Urochordata	2	4	2	4
TOTAL INVERTEBRATES	102	139	128	173
PHANEROGAMS	0	0	0	0
ALGAE	3	6	7	9
TOTAL PLANTS	3	6	7	9
TOTAL	105	145	135	182

Cnidarians are represented mostly by corals and gorgonians and specific hydroids. 37 species of sponges were identified, which is a remarkable biodiversity equivalent to 84% of sponges ideitified in Martinique. The habitat diversity and stability is favorable to the development of rare species on the Caribbean coast.

Remarkable species on this site:

Gorgonians	*Millepora complanata* *Iciligorgia schrammi* *Diodogorgia nodulifera* *Plexaura homomalla* *Eunicea mammosa* *Plexaurella sp.* *Plexaurella nutans* *Muricea pinnata* *Gorgonia mariae*

Corals	*Agaricia undata* *Mycetophyllia danaana* *Mycetophyllia aliciae* *Isophylia sinuosa*
Antipatharians	*Antipathes sp.* *Antipathes pennacea* *Antipathes lenta* *Plumapathes umbratica*
Hydroids	*Macrorhynchia clarkei* *Solanderia gracilis*
Echinoderms	*Davidaster discoidea*

- *Fish assemblage*

Species richness

90 species of fish belonging to 38 families.
Families with the lowest number of species are Serranidae (10 species), Labridae (9 species), Pomacentridae, Haemulidae and parrotfish (8 species), Lutjanidae (6 species), Holocentridae (4 species). Families such as Acanthuridae, Pomacanthidae, Chaetodontidae, Carangidae gather each three species.
28 species are classified "least concern" on the IUCN Red List. Two are classified as "vulnerable": *Lachnolaimus maximus* (Captain) and *Lutjanus analis* (Rowan).
Large predators are reported: *Carangoides ruber*, *Ocyurus chrysurus*, Sc*omberomorus regalis*, *Elagatis bipinnulata*, *Sphyraena barracuda*. Rare species were also observed: *Anisotremus surinamensis, Balistes vetula, Cantherhines macroceros, Calamus calamus, Cantherhines pullus, Centropyge argi, Epinephelus adscensionis, Epinephelus guttatus, Equetus punctatus, Haemulon striatum, Holacanthus ciliaris, Holacanthus tricolor, Kyphosus saltatrix, Lachnolaimus maximus, Lutjans analis, Melichthys Niger, Pareques acuminatus, Pomacanthus paru.*

Species richness / Family / Depth

- **0-10m:** 54 species. Labridae count 7 species, while Serranidae, Scaridae and Pomacentridae have 6 species in each family.
- **10-20m:** 69 species. The Labridae, Haemulidae and Pomacentridae are best represented (7 species each), followed by Serranidae and Scaridae with 6 species.
- **20-30m**: 60 species. Serranidae (10 species) are the most represented. Haemulidae include 7 species. Labridae, Lutjanidae and Pomacentridae total 5 species each.

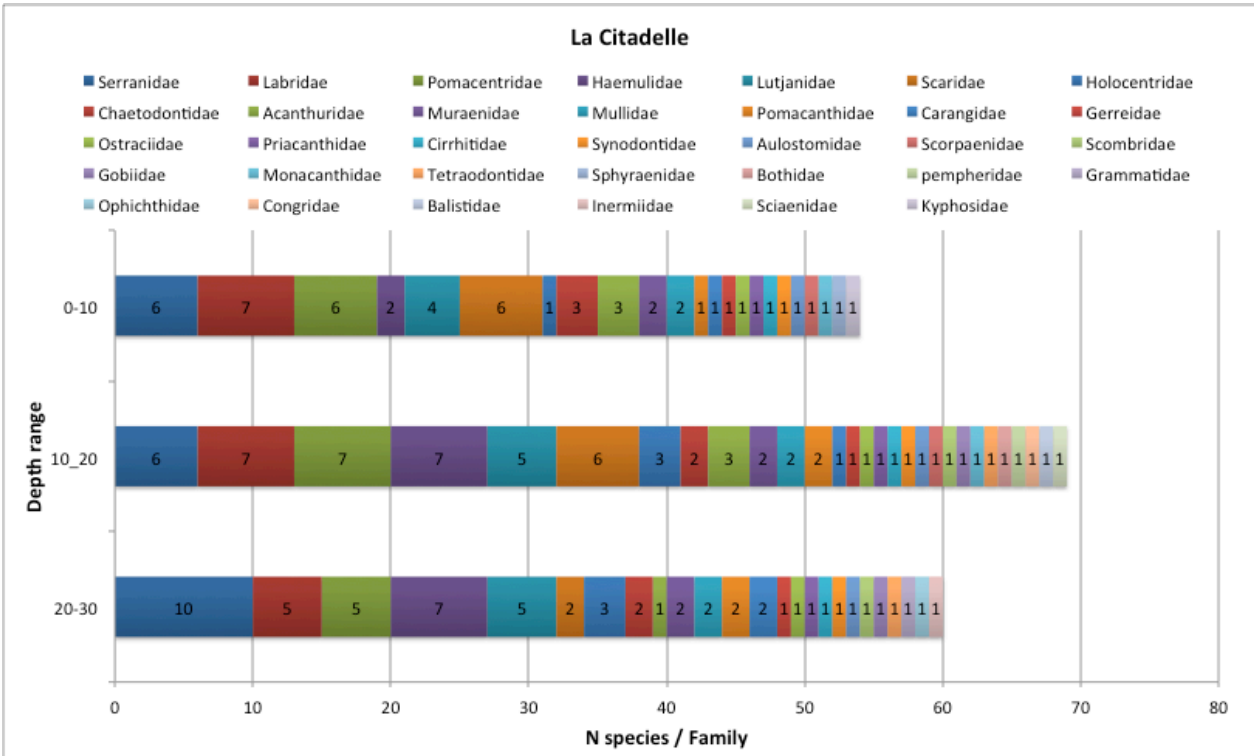


Figure 22. Fish species richness per family and depth range – Citadelle.

• Density and biomass / family

The average density is 1226 ± 410 ind / 200m² shared into 24 families. Only families with at least 1% of the total density of the site are represented in the figure X.

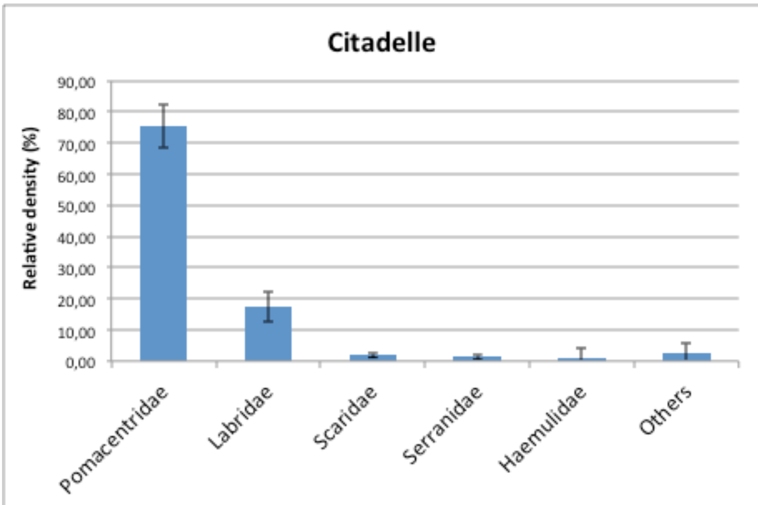


Figure 23. Average density of major fish families (± std error – families under 1% not represented) – La Citadelle.

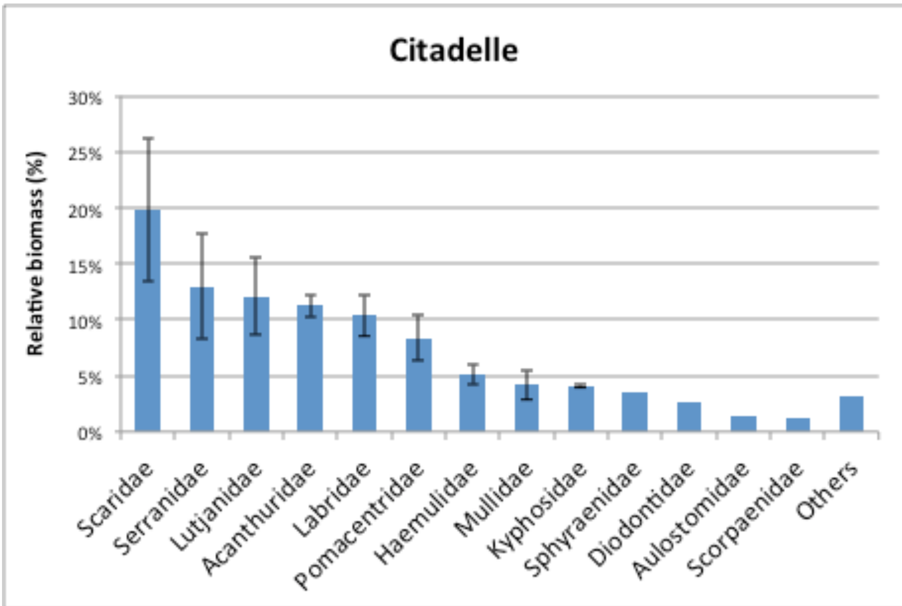


Figure 24. Average biomass of major fish families (± std error – families under 1% not represented) – La CItadelle.

Pomacentridae dominate fish populations at Citadelle, with an average of 76 ± 7% of the total assemblage. *Stegastes partitus* and *Chromis multilineata* are the major species of this family. Labridae account for 18 ± 5% of the total abundance, second contribution to the assemblage (*Thalassoma bifasciatum* being the main species). Scaridae, Serraniade and Haemulidae represent 5% of the total abundance. In these families, some species have a high commercial value (*Sparisoma aurofrenatum*, *Cephalopholis fulva*, *C. cruentata* and *Haemulon flavolineatum*).

The average biomass at Citadelle is 7269 ± 2521g / 200m². Four families contribute to more than half the total biomass of the assemblage Scaridae (20 ± 12%), Serranidae (13 ± 8%), the Lutjanidae (12 ± 12%) and Acanthuridae (11 ± 5%). The following families are the Labridae, Pomacentridae, Haemulidae, Mullidae, Kyphosidae, Sphyraenidae, Diodontidae, Aulostomidae and Scorpaenidae. Four species contribute up to 29% of the total biomass: *Sparisoma aurofrenatum* (7%), *Cephalopholis cruentata* (8%), *Lutjanus mahogany* (8%), and *Sparisoma viride* (6%), which are species of high commercial value.

✓ Trophic groups

Among the total abundance of the population, 89% are territorial herbivorous and planktivorous fishes. Despite these high values , they contribute very little to the biomass (13%). Carnivores represent 43% of the total biomass but are very low in terms of abundance (7%). Strict herbivores constitute 35% of the total biomass but only 2% of total abundance (Figure 18).

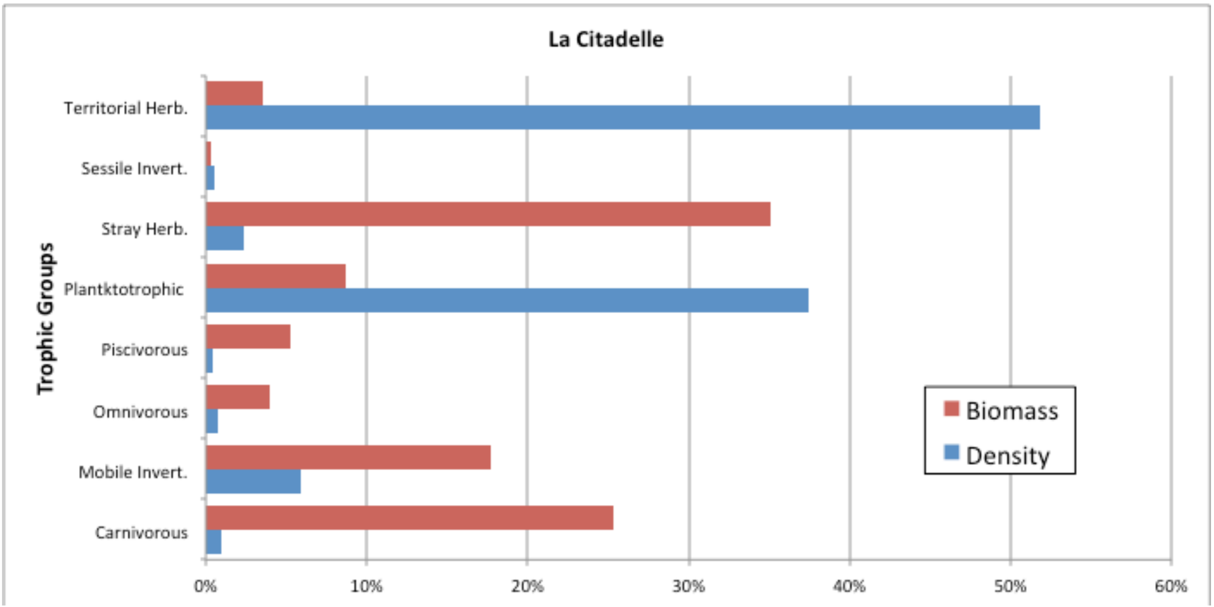


Figure 25. Fish density and biomass per trophic groups – Citadelle.

3.1.2.6. Babody North

❖ *Benthic cover*

Depth 30-20 m

The deep landscape is vertical basalt walls that form deep canyons. Sandy bottoms are steeply. The walls are covered with anthipatarians. The sponge community is diverse, including *A. conifera* (+++), *N. digitalis*, *S. coralliphagum* (+). Corals of the genus *Agaricia* (++) cover the walls along with *M. cavernosa* and species of the genus Porites. The communities also gather hydroids and sea fans. Dictyota algae are present, but the populations are moderate (+). Sedimentation is average on the site.

Going up the silty slope becomes steeper (45°) and Dictyota populations are more important. The sandy area is dotted with large, dense blocks covered by dominant sponges of the genus *Xestospongia*, along with *A. conifera*, *C. vaginalis*, *C. plicifera* and *Syphonodyction*. The majority of corals are *M. mirabilis*, *M. decactis*, *M. meandrites* and genus *Cladocora*. Beside Dictyota other algae species include *Halimeda tuna* (calcareous algae), *Lobophora* and *Avrainvilea*. The benthic comunity is also composed of numerous hydroids and actinarians.
Around 20m is a rocky area covered by many *Xestospongia* sponges (+++). Dictyota algae are very abundant (+++). Some areas of coral debris, but are covered with abundant blue-green algae.

Depth 20-10m

Above the canyons, a 20° silty slope extends to the shallows. Rock boulders are colonized by sponges (*X. muta* +++, *I birotulata*, *C. plicifera*, *N. digitalis*, *E. ferox*) and *DIctyota* algae (+++).

Few coral species of small size are identified as *S. Siderea*, *P. Porites*, *P. astreoides*, *M. decactis*, *Agaricia sp*, *M. meandrites*.

Seagrass meadows develop between the boulders around 15m. They are mainly composed of short, dense plants of *Halophila stipulacea* and heavily silted. Some *S. vesparium* sponges specimens are present.

Depth 10m
At shallow depth, sandy bottom is covered by seagrass and algae (*Padina*). Some rocks are covered by sponges of the genus *Aplysina*.
Halophila is patchy distributed in a Syringodium population. Some sponges are also present including *Syphonodictyon coralliphagum*, and cyanobacterias cover the seagrass.

The benthic community is characterised by three major types: coral communities, seagrass communities and soft bottom communities. Quantitative data is then not representative of a homogeneous site, as it is the difficulty to find a continuous ecosystem on this sector to deploy transects over a distance of 50m (the basic unit for describing biocenotic sets in the tropics).
Therefore, corals represent only 2.7% of the communities, and are concentrated at the top of the canyon, on the ridges of lava. The site generally has a high algae population (35.6%), reflecting a deteriorated health condition. The most interesting communities are located on the vertical walls of canyons, which cannot be taken into account when using transect methods (Figure 19).

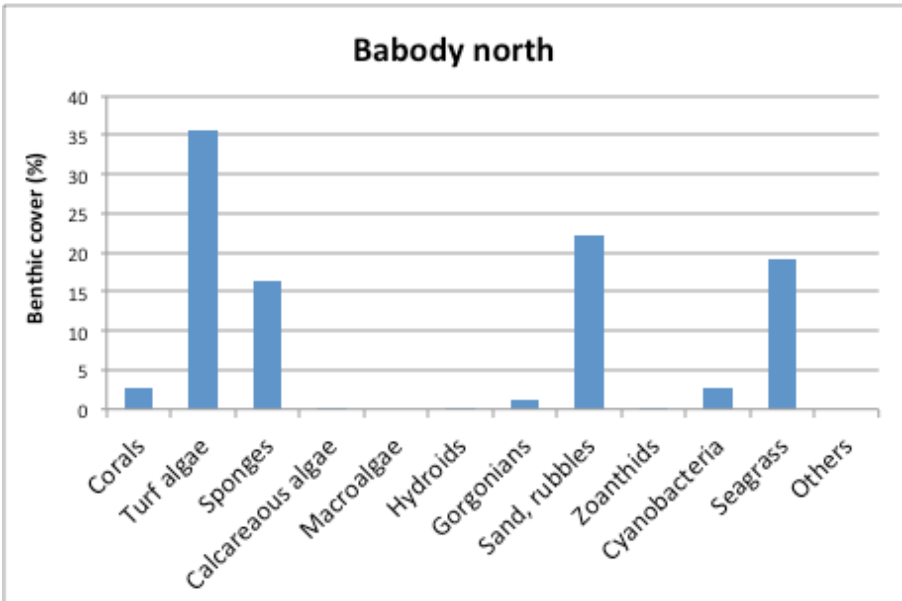


Figure 26. Benthic cover % - Babody north.

❖ *Benthic species inventory*

The site is characterised by deep canyons down to 30m, an intermediate area with rocks and seagrass, and shallow seagrass beds and sandy environment. The biodiversity associated to the dense and stable seagrass meadows acting as a nursery for juvenile fish and providing habitat for many molluscs and arthropods.

This complex habitat area has 161 animal species, mostly sponges and cnidarians. The high proportion of arthropods, annelids and echinoderms is related to the complexity of the canyons, offering many habitats. Cnidarians show the predominance of corals but also hydroids. Antipatharians were also recorded (black coral). This site harbors 34 species of sponges which correspond to 77% of the sponge species identified in Martinique (Table 6).

Table 6. Species richness per groups and depth range - Site Babody Nord

	Depth range			
	30-20m Drop-off / Canyons	20-10m Volcanic rocks	10-0m Seagrass / sand	Total number of species
Porifera	30	33	1	34
Cnidaria	28	54	2	57
Ctenophora	0	0	0	0
Platylminthes	0	0	0	0
Annelida	9	13	4	13
Bryozoa	2	1	1	2
Echinodermata	5	14	2	16
Arthropoda	5	21	7	26
Mollusca	0	7	3	9
Urochordata	3	3	0	4
TOTAL INVERTEBRATES	82	146	20	161
PHANEROGAMS	0	0	2	2
ALGAE	4	14	10	22
TOTAL PLANTS	4	14	12	24
TOTAL	86	160	32	185

Habitat diversity and stability are favorable to the development of a number of species rare on the Caribbean coast.
The specific biodiversity is increased by the presence of a seagrass beds (shellfish).

Remarkable species on this site:

Telestinae	*Carijoa riisei*
Corals	*Mycetophyllia aliciae*
Antipatharians	*Antipathes sp.* *Antipathes lenta* *Plumapathes umbratica*
Zoanthids	*Isaurus tuberculatus*
Annelids	*Eunice sp.*
Echinoderms	*Davidaster discoidea*

❖ *Fish assemblage*

- Species richness

80 species of fish belonging to 25 families.

Families with the lowest number of species are the Serranidae (12 species), Labridae (9 species), Pomacentridae (8 species), parrotfish (7 species), Haemulidae (6 species), Lutjanidae (5 species), and Holocentridae Chaetodontidae (4 species).

Twenty six species are classified as "least concern" (least concern) on the IUCN Red List. Two are classified as "vulnerable": *Balistes vetula* and *Lutjanus analis*. Large predators are reported: *Carangoides ruber*, *Ocyurus chrysurus*, *Scomberomorus regalis*. Rare species were also observed: *Centropyge argi*, *Lutjanus analis*, *Melichthys niger*, *Balistes vetula*.

- Species richness per family per depth

0-10m: 37 species. 7 species belong to the family Serranidae, 4 to Labridae and Parrotfish. Pomacentridae, Haemulidae and Chaetodontidae count only 3 species.

10-20m: 69 species. Serranidae are best represented with 10 species. Labridae include 7 species. The Haemulidae, Pomacentridae and Scaridae total 6 species each, followed by the Lutjanidae with 5 species.

20-30m: 57 species. Serranidae count 10 species and Labridae 7 species. Pomacentridae include 5 species. Scaridae, Haemulidae and Lutjanidae only have 4 species per family.

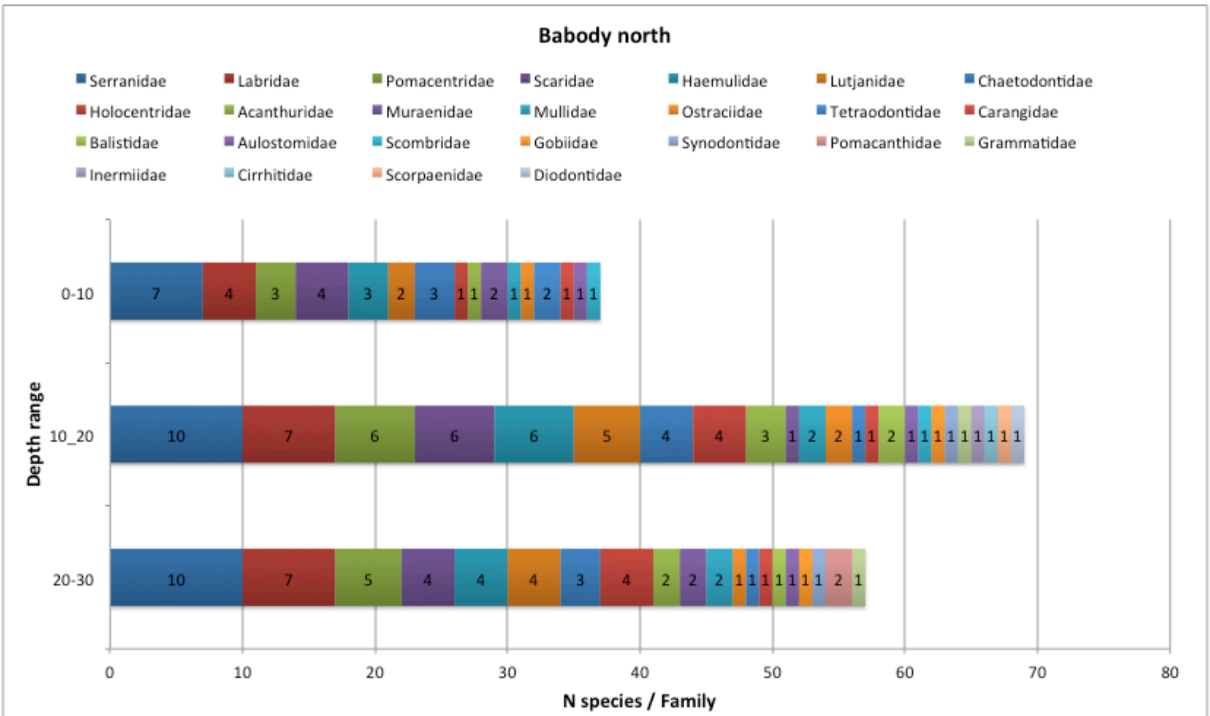


Figure 27. Fish species richness per family and depth range - Babody north.

- Density and biomass / family

The average abundance is 551 ± 155 ind / 200m² divided into 14 families. Only families with at least 1% of the total density of the site are represented in figure X.

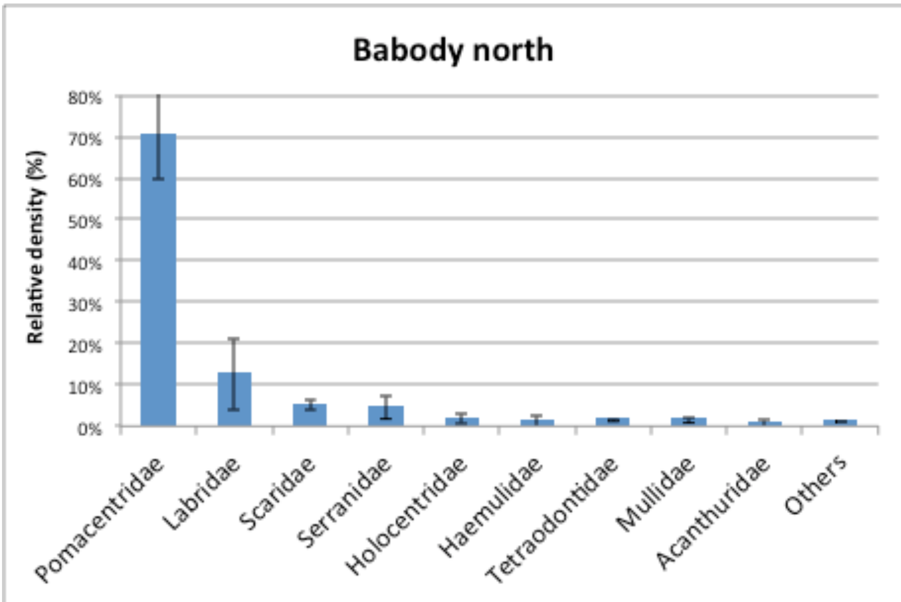


Figure 28. Average density of major fish families (± std error – families under 1% not represented) – Babody north.

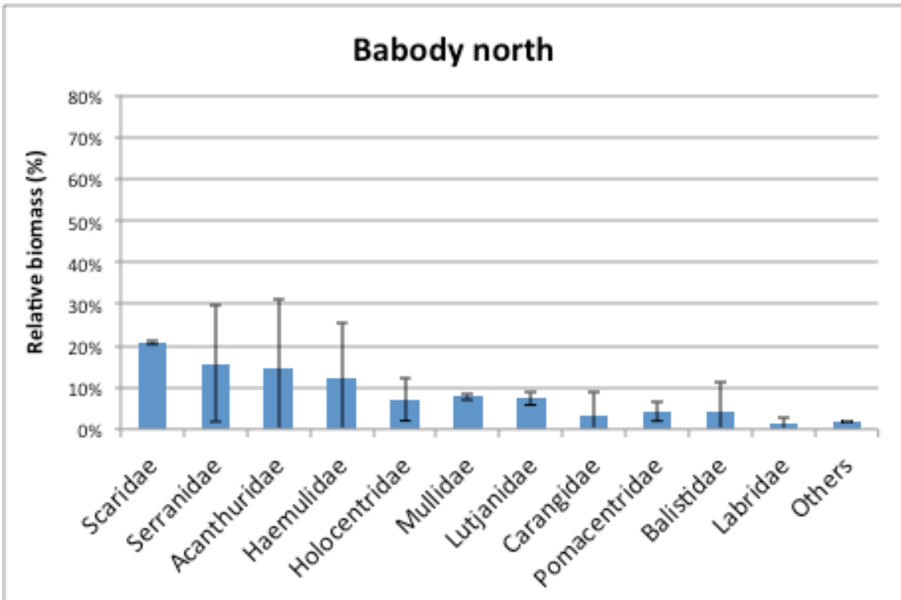


Figure 29. Average biomass of major fish families (± std error – families under 1% not represented) – Babody north.

The Pomacentridae dominates the fish populations with an average of 70 ± 11% of the total abundance. *Stegastes partitus* represents more than half of the abundance of this family. The Labridae account for 13 ± 9% of the total abundance. Scaridae and Serranidae each account for 5% of the total abundance, and 2% for the Holocentridae.
The average biomass is 5346 ± 2944 g/200m², representing 11 families: Scaridae (21 ± 0%), Haemulidae (12 ± 13%), Acanthuridae (15 ± 17%), and Serranidae (16 ± 14 %). These families together contribute more than half the total biomass of the population. Lutjanidae and Holocentridae represent 7% of the biomass, and Mullidae 8%. Four species represent 30% of the total biomass: *Acanthurus chirurgus* (12 ± 12%), *Sparisoma aurofrenatum* (8 ± 8%), *Scarus taeniopterus* (10 ± 5%). These species have a high commercial value. Strong standard errors on biomass values show that there is a great disparity between transect at the same site.

- Trophic groups

Territorial herbivorous fish represent 55% of the total abundance and 23% are planktivorous fishes. Despite these high values, these two groups contribute very little to the biomass (3% and 6%). Strict herbivores represent 35% of the biomass but only 6% of the total abundance. Mobile invertebrates consumers and carnivores contribute respectively to 28 and 22% of the total biomass. Their densities range between 3 and 10% (Figure 23).

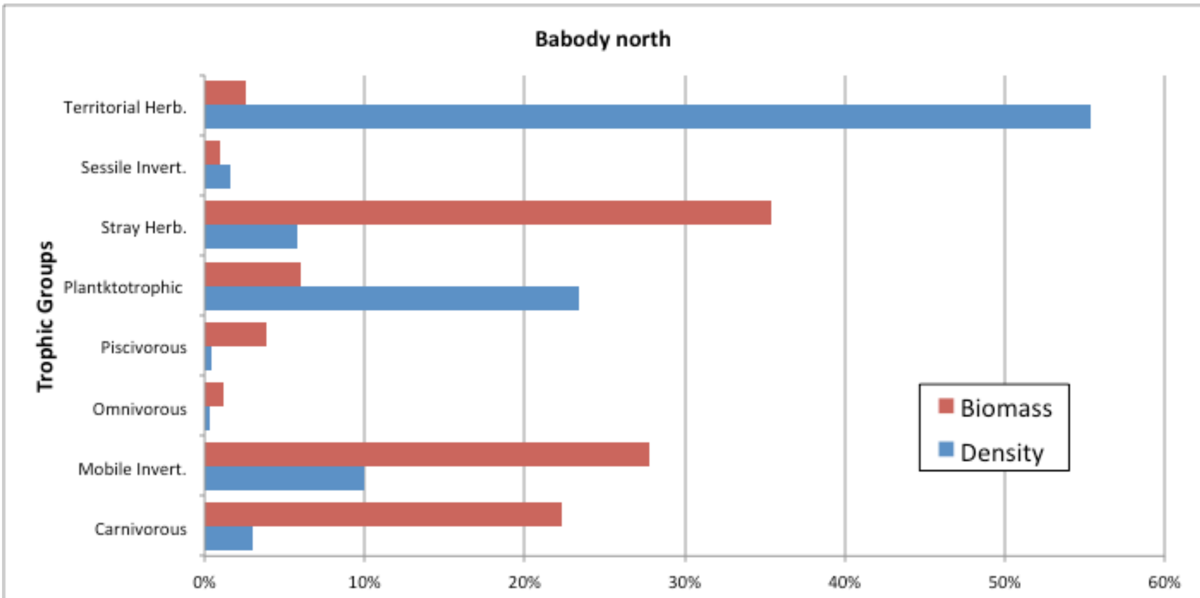


Figure 30. Fish density and biomass per trophic groups – Babody north

3.1.2.7. Babody South

- *Benthic cover*

Depth 30-20 m

The area is characterized by basaltic flows in grooves and drop-offs that plunge down to the deep. The walls are vertical and the sandy slope is 45°. Deep communities are characterized by *X. muta* (++), *A. conifera* (+++), *Aplysina sp*, *I. strobilina*, *C. vesparium*, *N. digitalis*, *G. vaginalis*, and *C. Neptuni* and *C. plicifera*. The algal population is composed of Halimeda species (++) around 30m, along with *Dictyota* and *Lobophora*. On the sandy areas cyanobacteria are very abundant. Large colonies of coral *Agaricia* species in very good condition are observed. Other coral species, including *O. faveolata*, *M. meandrites*, *S. Siderea* are observed predominantly. Some Gorgonians are identified and Palythoa.

Depth 20-10 m

Many *X. muta* sponges developed on the basaltic spurs. Going up the slope, dense and silted (++) *Halophila* seagrass extend from the canyons. In these meadows, large rocky reefs are covered with *X. muta* (++) and *E. ferox* sponges. Diseased specimens of *X. muta* are observed. These two major species are accompanied by *Calyspongia sp.*, *Geodia*, *Niphates* and *Cliona* sp. *O. faveolata*, *M. meandrites*, *S. Siderastrea*, *P. Porites*, *M. decactis* are the major coral species. *Agaricia*, *Cladocora* and *Dichoceania* are present but in low abundance. *Ventricaria ventricosa*, *Dictyota sp.* and *Avrainvilea sp.* are identified are major algae species.

Depth 10-0 m

The tops of the ridges continue with Halophila seabeds and rock boulders covered by *X. muta* and *Calyspongia sp.* Dictyota algae are well represented and develop over the seagrasses. Other algae species as *Penicillus* and *Halimeda* are identified. This *Halophila* seagrass bed develops over a previous *Syringodium* area. The dense seagrass extends to a patchy distribution.

- *Benthic species inventory*

The site presents successively from 30m canyons landscape, seagrass beds and a sandy environment. Because of its characterisctics it is highly favorable to a high biodiversity. The continuity between ecosystems enables the development of species generally deeper. The dense and stable seagrass bed acting as nursery for juvenile fish provides also micro-habitats for many molluscs and arthropods. The presence of cyanobacteria is characteristic of pollution impact.

164 animal species were inventoried, mainly cnidarians and sponges. The high proportion of arthropods, annelids and echinoderms is in line with the complexity between rocky areas and seagrass, offering diverse habitats. Cnidarians are dominated by corals, but also hydroids and sea fans on rock and seagrass. Antipatharians (black coral) are present on rocky substrates. 32 different species of sponges are identified, representing 73% of the known species of Martinique (Table 7).

Table 7. Species richness per groups and depth range - Site Babody Sud

	Depth range			
	30-20m Drop-off / Canyons	20-10m Volcanic rocks	10-0m Seagrass / sand	Total number of species
Porifera	30	23	1	32
Cnidaria	29	59	2	64
Ctenophora	0	0	0	0
Platylminthes	0	0	0	0
Annelida	8	13	6	15
Bryozoa	2	1	1	2
Echinodermata	4	10	3	12
Arthropoda	5	18	8	24
Mollusca	2	6	4	10
Urochordata	3	3	0	4
TOTAL INVERTEBRATES	83	134	25	164
PHANEROGAMS	0	0	2	2
ALGUES	4	12	10	21
TOTAL PLANTS	4	12	12	23
TOTAL	87	146	37	187

Remarkable species on this site:

Gorgonians	*Plexaura homomalla* *Plexaurella sp.* *Carijoa riisei*
Corals	*Mycetophyllia aliciae*
Antipatharians	*Antipathes sp.* *Antipathes lenta* *Plumapathes umbratica*
Zoanthids	*Isaurus tuberculatus*
Platyhelminths	*Pseudoceros bicolor*
Echinoderms	*Davidaster discoidea*

❖ *Fish assemblage*

- Species richness

81 fish species belonging to 27 families.
Families with the lowest number of species are the Serranidae (15 species), Haemulidae (9 species), Pomacentridae and Lutjanidae (8 species), parrotfish and Labridae (5 species), Carangidae (4 species). 21 species are classified as "least concern" (least concern) on the IUCN Red List. Two are classified as "vulnerable": *Lutjanus cyanopterus* and *Lutjanus analis*. One is classified as "near threatened": *Aetobatus narinari*.
Large predators are reported: *Caranx crysos*, *Carangoides ruber*, *Ocyurus chrysurus*, *Scomberomorus regalis*, *Elagatis bipinnulata*. Rare species were also observed: *Aetobatus narinari*, *Aluterus monoceros*, *Anisotremus surinamensis*, *Epinephelus adscensionis, Epinephelus guttatus*, *Kyphosus saltatrix*, *Lutjanus analis*, and *Lutjanus cyanopterus*.

- Species richness / family / depth

0-10m: 17 species. This area is mainly covered with seagrasses, which explains the difference of diversity with the deep areas that are characterized by different habitats. Labridae and Serranidae gather 3 species, while Pomacentridae, Lutjanidae and Mullidae total 2 species in each family.
10-20m: 72 species. The Serranidae are the most represented with 14 species. Haemulidae account 8 species and Pomacentridae 7 species, followed by Lutjanidae with 6 species, Labridae and Scaridae with 5 species each.
20-30m: 50 species. The Haemulidae gather 9 species, the Lutjanidae 7 species and the Serranidae total 6 species.

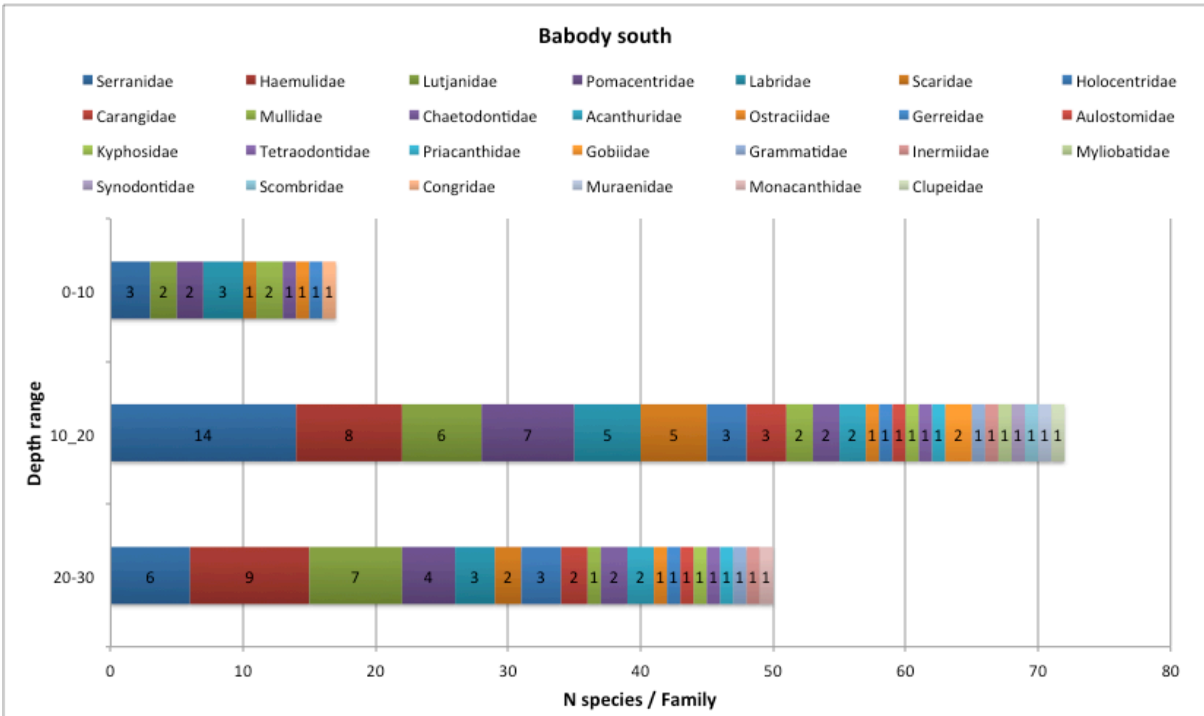


Figure 31. Fish species richness per family and depth range - Babody south.

- Density and biomass / family

Babody sud has an average abundance of 564 ± 198 ind/200m² repesenting 19 families. Only families with at least 1% of the total density are represented in figure 25.

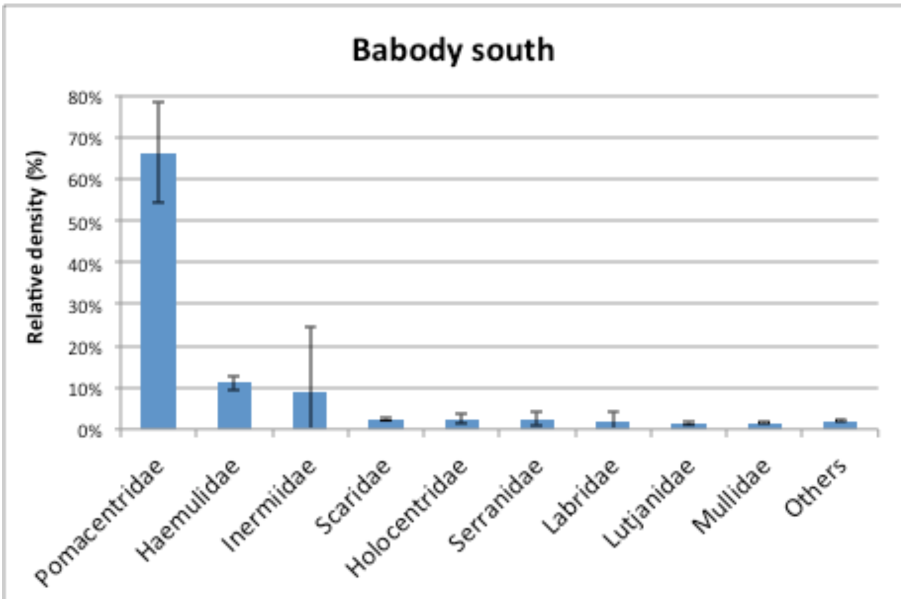


Figure 32. Average density of major fish families (± std error – families under 1% not represented) – Babody south.

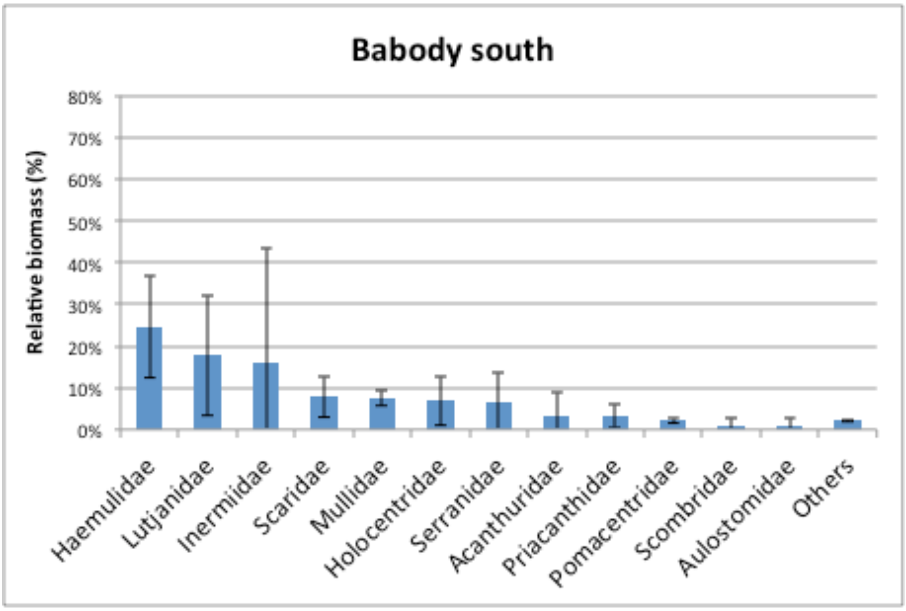


Figure 33. Average biomass of major fish families (± std error – families under 1% not represented) – Babody south.

The Pomacentridae dominate the fish population with an average of 66 ± 12% of the total abundance. *Stegastes partitus* and *Chromis multilineata* are the major species of this family. The Haemulidae account for 11 ± 2% of the total abundance (*Haemulon chrysargyreum* being the main species). The Inermiidae total 9 ± 16%. Other families marginally contribute to the abundance, between 1 and 2%.
The average biomass is 7871 ± 4975g/200m². The Inermiidae (16 ± 28%), Haemulidae (25 ± 12%), and Lutjanidae (18 ± 14%) contribute to more than half of the total biomass of the population. 16% of the biomass is composed of Scaridae (8 ± 5%) and Mullidae (8 ± 2%), followed by Holocentridae (7 ± 6%), Serranidae (6 ± 7%) and Acanthuridae (3 ± 6%). Three species account for 51% of the total biomass (*Inermia vittata* (16%), *Haemulon chrysargyreum* (22%), *Lutjanus mahogoni* (13%)). Strong standard errors on biomass values show that there is a great disparity between transect at the same site.

- Trophic groups

The assemblage is composed of 43% planktivorous fish and 36% territorial herbivorous fish. Consumers of mobile invertebrates contribute up to 14%. Despite these high values of abundance, territorial herbivores marginally contribute to the biomass (1%), planktivorous 23% and consumers of mobile invertebrates 37%. Strict herbivores represent 11% of the biomass but only 3% of the total abundance. Carnivores contribute to 24% of the biomass and 4% of the abundance (Figure 27).

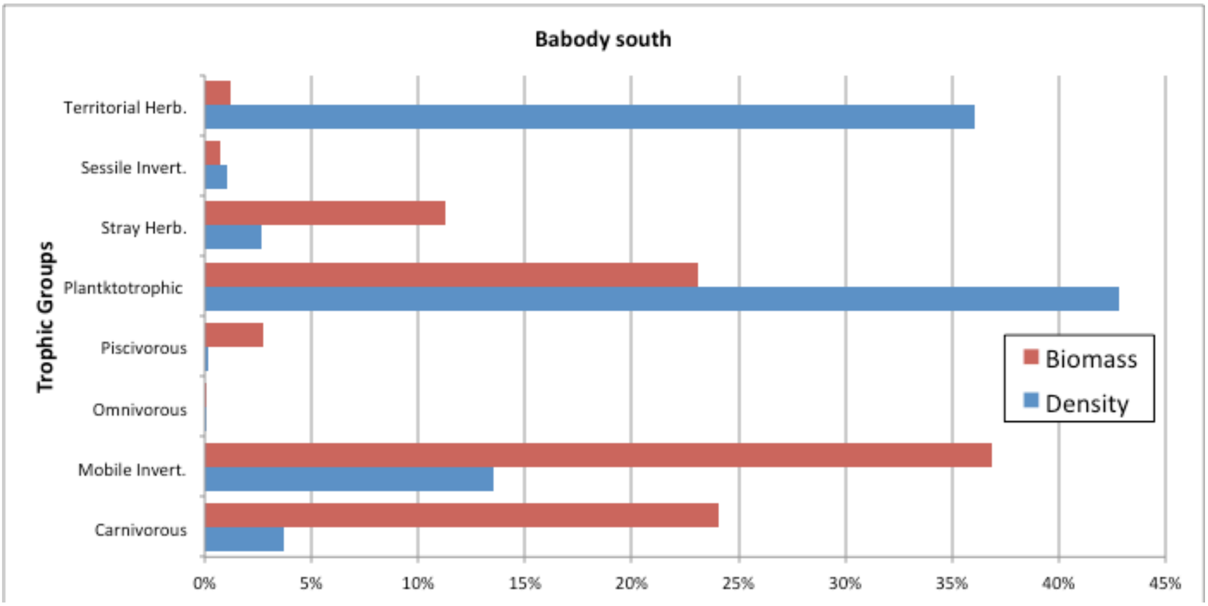


Figure 34. Fish density and biomass per trophic groups – Babody south

3.1.2.8. Pointe Lamare west

❖ *Benthic cover*

Depth 30-20 m
The site is a gentle sandy slope (30°) with gravels and rubbles at the bottom. The community is composed of numerous sponges (X. muta, C. plicifera, A. conifera, S. vesparium, I. birotulata). Cyanobacteria cover the sand in large areas (+++). The coral population is mainly composed of M. cavernosa, Agaricia sp, M. decactis and E. fastigiata. Hydroids are abundant (++), and Palythoa, Zoanthus and Discosoma genus are frequent. Sedimentation is rather large and hard bottom is covered by Dictyota.

Depth 20-10 m
An important Dictyota algae population (+++) is observed. The sandy areas are interspersed with gravel areas. Sponges X. muta (+++) are well represented and the hard substrate is heavily covered with encrusting sponges. This ecosystem is further characterized by gorgonians. Corals are very small sizes, mainly represented by M. meandrites, E. fastigiata, P. mirabilis and M. astreoïdes.
At 15m, strict Halophila seabeds extend and are covered with cyanobacteria. A large population of Halimeda genus algae is mixed with the seagrasses.
In this sector, sponge species E. ferox and I. birotulata are widely represented. The hard substrates and massive sponges are covered with hydroids. The sandy plateau at 11m has large population of eels (SPECIES).

Depth 10-0 m

The shallow area is sand with large boulders. Halophila patches develop between these blocks. The hard substrate is heavily colonized by hydroids and many encrusting sponges. Halimeda algae are observed in seagrass areas as well as high densities of cyanobacteria.
Padina algae are found in the sand.
At 6m, large rocks are covered with hydroids. Around these rocks, a large gorgonian population has developed.

The benthic community is characterized by a strong occurence of macroalgae (31.6%), sponges (13.8%) and corals (11.9%). The site is complex, with alternating type of coral communities and soft substrate areas (21%) and seagrass beds (11.3%). The presence of cyanobacteria around 3% is a sign of nitrogen pollution (Figure 28).

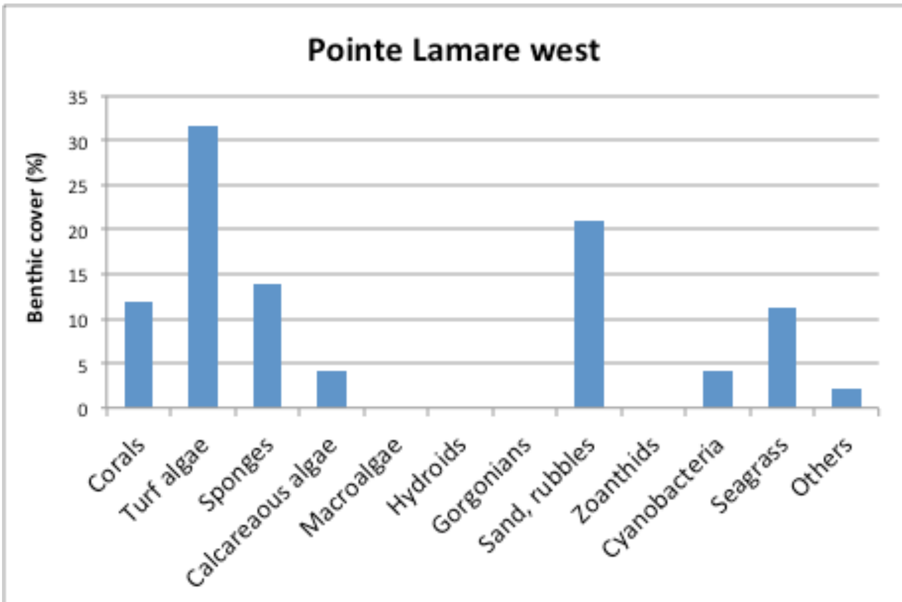


Figure 35. Benthic cover % - Pointe Lamare west.

❖ *Benthic cover*

The site successively froms a 30m vertical drop, an intermediate zone and a dense seagrass shallow area. The varied habitats offer a large number of species. The site is exposed to a steady stream, which supports the development of hydroids. Environmental conditions allow the development of corals, sponges and other groups on the intermediate reef. The presence of a dense and continuous seagrass bed greatly increases biodiversity in molluscs and arthropods and constitutes a nursery for juvenile fishes. This site is one of the richest in biodiversity amog the 15 sites studied, with the Citadelle site.

190 animal species, mainly cnidarians and sponges, were identified. The high proportion of arthropods, annelids and echinoderms is related to the complexity of the site offering varied habitats.
Cnidarians are predominant among corals, together with hydroids. It should be emphasized the presence of antipatharian (black coral). 35 species of sponges were listed. It represents 80% of the species identified in Martinique (Table 8).

Table 8. Species richness per groups and depth range - Site Pointe Lamare Ouest

	Depth range			
	30-20m Drop-off	20-10m Volcanic rocks	10-0m Seagrass / Sand	Total number of species
Porifera	28	34	0	35
Cnidaria	34	65	11	71
Ctenophora	0	0	0	0
Platylminths	0	0	0	0
Annelida	7	17	4	19
Bryozoa	2	2	1	3
Echinodermata	7	14	4	16
Arthropoda	7	25	10	30
Mollusca	1	7	9	12
Urochordata	3	3	0	4
TOTAL INVERTEBRATES	89	167	39	190
PHANEROGAMS	0	2	2	2
ALGAE	5	12	8	17
TOTAL PLANTS	5	14	10	19
TOTAL	94	181	49	209

Remarkable species on this site:

Gorgonians	*Eunicea mammosa*
Corals	*Mycetophyllia aliciae* *Colangia immerse*
Telestacea	*Carijoa riisei*
Antipatharians	*Antipathes sp.* *Antipathes lenta* *Antipathes pennacea* *Plumapathes umbratica*
Zoanthids	*Isaurus tuberculatus*
Annelids	*Eunice sp.* *Mesochaetopterus sp. (rogeri)*
Platyhelminths	*Pseudoceros bicolor*
Echinoderms	*Davidaster discoidea* *Astropyga magnifica*
Crustaceans	*Stenopus scutellatus*

❖ *Fish assemblage*

- Species richness

83 species belonging to 30 families.

Families with the lowest number of species are the *Serranidae* (10 species), *Pomacentridae* and *Haemulidae* (8 species), *Labridae* and parrotfishes (7 species), and *Lutjanidae* (5 species), *Carangidae* and *Holocentridae* (4 species).
Twenty six species are classified "least concern" on the IUCN Red List. One is classified as "vulnerable" *Lutjanus analis* and one "insufficient data" *Dasyatis americana*.
Large predators are reported on this site: *Carangoides ruber*, *Ocyurus chrysurus*, *Scomberomorus regalis*, *Elagatis bipinnulata*. Rare species were also observed: *Anisotremus surinamensis*, *Cantherhines macroceros*, *Cantherhines pullus*, *Centropyge argi*, *Epinephelus guttatus*, *Equetus lanceolatus, Holacanthus tricolor*, *Kyphosus saltatrix*, *Lutjanus analis*, *Melichthys Niger*, *Pomacanthus paru*, *Dasyatis americana*.

- Species richness / family / depth

0-10m: 51 species. Labridae and Scaridae account 6 species, while Pomacentridae total 5 species. Serranidae and Haemulidae include 4 species. Lutjanidae, Holocentridae, and Acanthuridae follow with 3 species.
10-20m: 54 species. Serranidae is well represented (7 species), followed by Labridae (6 species). Pomacentridae, Haemulidae and Carangidae count 4 species.
20-30m: this depth range is the richest in terms of species diversity with 59 species recorded. Serranidae has the largest number of species (9 species). The Haemulidae total 7 species, Labridae and Pomacentridae 6 species. Parrotfish and Lutjanidae represent 5 species each.

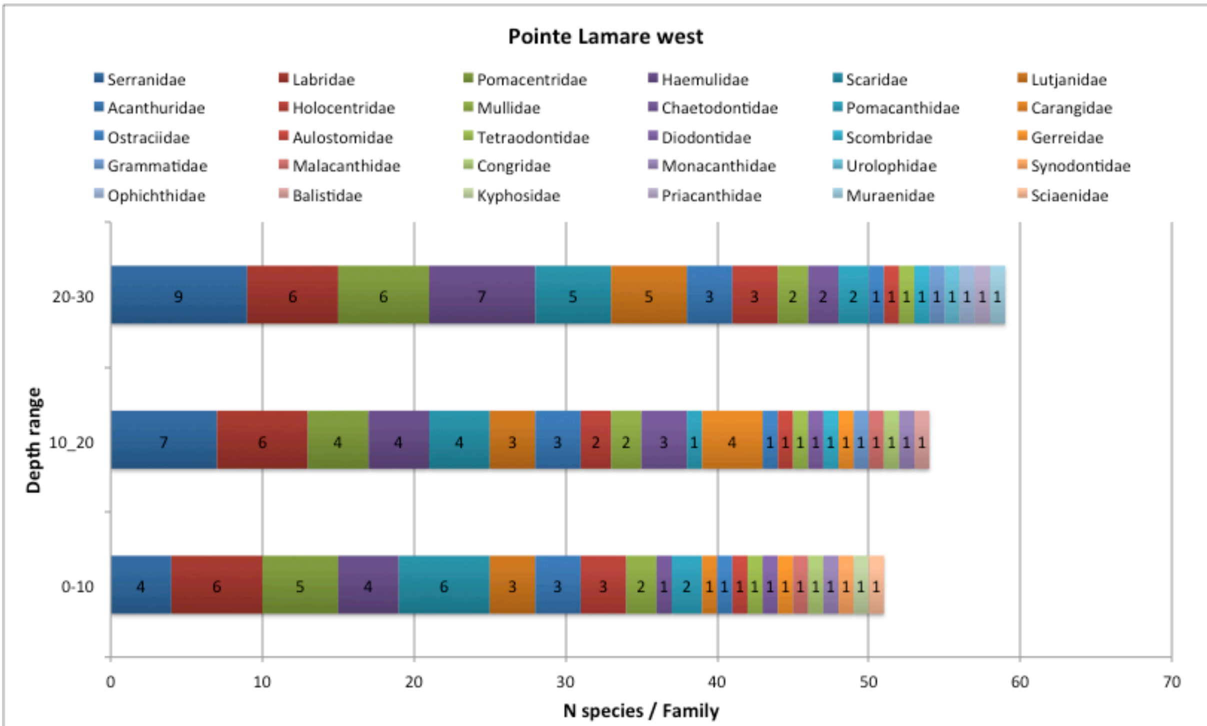


Figure 36. Fish species richness per family and depth range - Pointe Lamare west

3.1.2.9. Pointe Lamare east

Depth 30-20 m
The site is composed of basalt flows on a sandy bottom. Numerous sponges have colonised these substrates including X. muta (+++), A. fistularis, C. vaginalis and C. plicifera (++), A. conifera (+++) and I. birotulata (++). The drop-offs are also covered with hydroids (+++) and Zoantharians.
Small coral colonies develop as M. cavernosa, P. Porites and P. astreoides, M. decactis and M. mirabilis, S. Siderea.
The algae population is represented mainly by the Dictyota.
Sedimentation is medium to strong.

Depth 20-10 m
The gorgonian population is well developed, especially Pseudopterogorgia. The area is very similar to previous to about 15m depth. By 15m, the lanscape significantly changes with high cover with cyanobacteria and Dictyota and sedimentation, alternating with hard substrate areas.
Large rocks are covered with sponges: X. muta (+++), I. birotulata (+++), S. vesparium (++), I. strobilina, C plicifera and C. vaginalis. Ectyoplasia ferox encrusting form is very abundant (+++). Hydroids are also very abundant (+++).
Annelid worms (tube worms) from genus Hermodice, Bispira, Eupolymnia are widely represented.
Corals population is not well developed and colonies are small. The major species are E. fastigiata, M. meandrites (++), S. Siderea and Agaricia species.
From 15 m, the sandy slope alternates with gravel areas and rocks colonized by sponges, hydroids, small coral colonies and Dictyota). Gorgonians are also very abundant, along with Aplysina sponges. Soft bottoms are covered with cyanobacterias and Padina algae.

Depth 10-0 m
In the shallow area, a sandy plateau with scattered rock bouldres form the landscape. Many gorgonians and X. muta sponges consitute the biocenose. Among the most common species of sponges, Aplysina (++) and I. birotulata (++) are the most abundant. The bottom is covered with cyanobacterias (++).
Corals are represented by meandrina meandrites essentially. Rocks are covered with Millepora sp. (++++) and P. astreoides.
Dictyota are very abundant and sedimentation is very strong.

The maximum biodiversity area 20-10m has a high proportion of soft substrate (45%). About 28% of the hard substrate is covered by a dense algal community, along with sponges up to 18%. Both cover 46% of the bottom, leaving very little space for the development of corals (1.7%) (Figure 30).

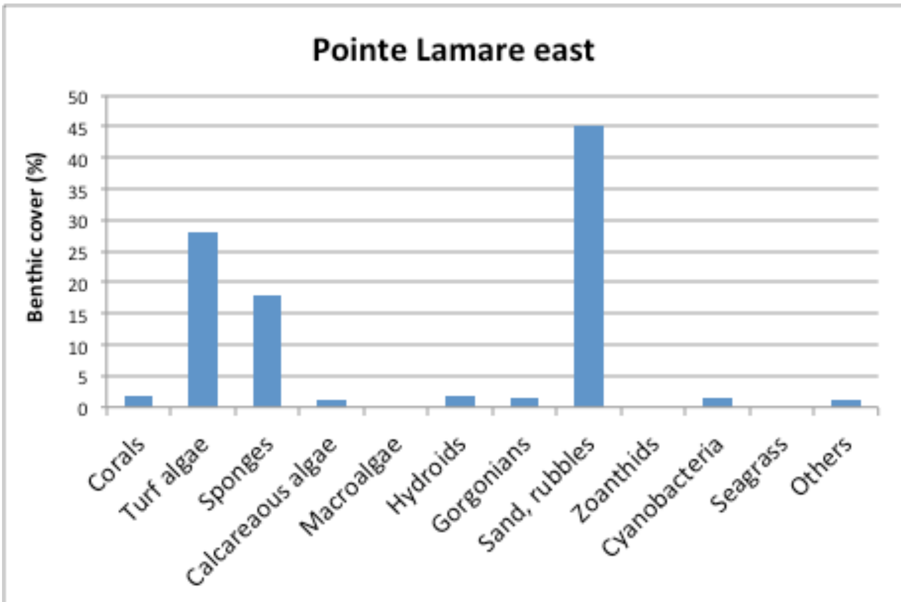


Figure 37. Benthic cover % - Pointe Lamare east.

❖ *Benthic cover*

The site extends from 30m with a gentle sandy slope facies along with seagrass areas. The geomorphology offers varied habitats for the installation of a large number of species. Connectivity between ecosystems is significant in favour of the development of numerous species.

119 animal species were sampled, with a majority of cnidarians and sponges characteristics of coral communities. The proximity of the seagrass beds promotes species diversity.
Among cnidarians corals and hydroids are predominant.
29 species of sponges were described, corresponding to 66% of the species identified in Martinique (Table 9).

Table 9. Species richness per groups and depth range - Site Pointe Lamare Est

	Depth range			
	30-20m Drop-off	20-10m Volcanic rocks	10-0m Seagrass / Sand	Total number of species
Porifera	29	1	0	29
Cnidaria	31	5	3	34
Ctenophora	0	0	0	0
Platylminths	0	0	0	0
Annelida	14	6	5	15
Bryozoa	1	0	1	2
Echinodermata	9	2	3	13
Arthropoda	14	4	3	17
Mollusca	3	3	3	6
Urochordata	3	0	0	3
TOTAL INVERTEBRATES	104	21	18	119
PHANEROGAMS	1	2	0	2

ALGAE	15	8	4	21
TOTAL PLANTS	16	10	4	23
TOTAL	120	31	22	142

Only one rare species was observed: *Hypsicomus sp.* (Annelid)

- *Fish assemblage*

- Species richness

89 species belonging to 33 families.

Families with the lowest number of species are the Serranidae (11 species), Labridae and parrotfish (8 species), Pomacentridae and Haemulidae (7 species), and Lutjanidae Holocentridae (5 species). Families such as Acanthuridae and Chaetodontidae gather each 3 species.

27 species are classified "least concern" on the IUCN Red List. Another is classified as "vulnerable": Lutjanus analis.

Large predators are reported: Carangoides ruber, Ocyurus chrysurus. Rare species were also observed: Cantherhines macroceros, Cantherhines pullus, Epinephelus guttatus, equetus punctatus Holacanthus tricolor, Kyphosus saltatrix, Lutjanus analis, Melichthys Niger, Pareques acuminatus, Pomacanthus paru.

- Species richness / family / depth

0-10m: 65 species. Labridae and Scaridae are represented by 7 species, while Serranidae and Pomacentridae total 6 species, followed by Lutjanidae (5 species), Haemulidae and Holocentridae (4 species)

10-20m: 74 species recorded. The Serranidae are best represented (10 species), followed by parrotfish and Labridae (7 species). The Haemulidae account 6 species.

20-30m: 56 species. The Serranidae has the largest number of species (9). Scaridae and Haemulidae total 6 species each.

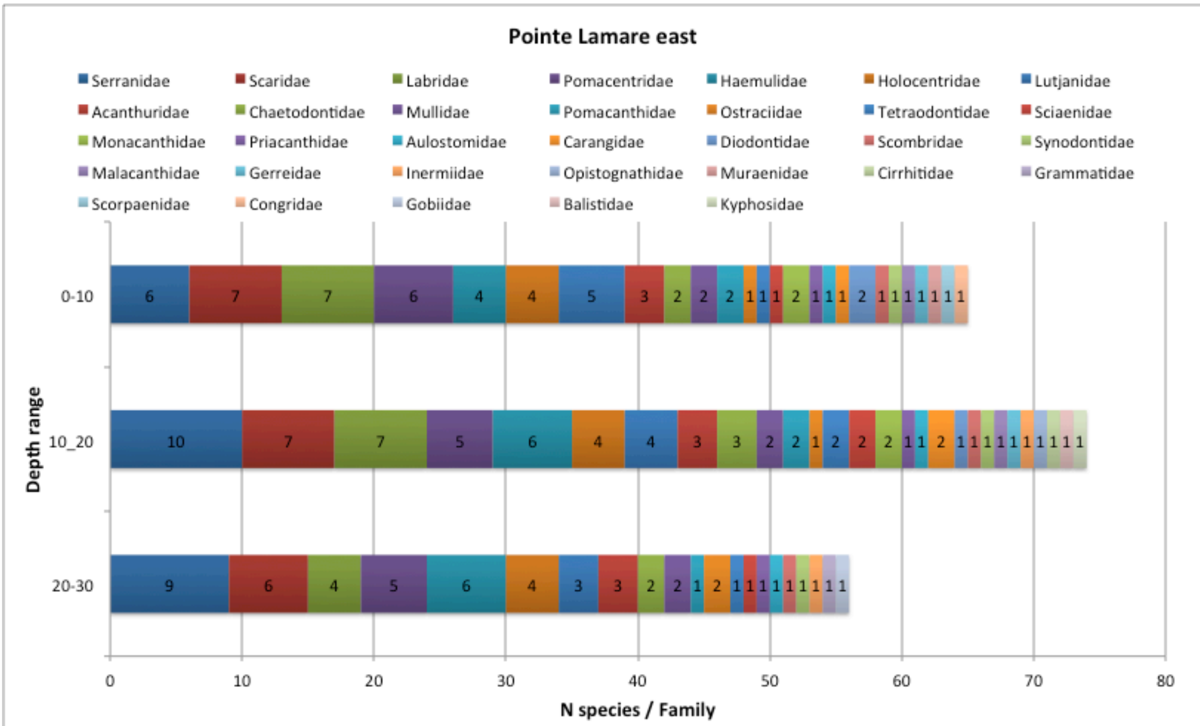


Figure 38. Fish species richness per family and depth range - Pointe Lamare east

- Density and biomass / family

The total abundance is 476 ± 298 ind/200m² for 19 families. Only families with at least 1% of the total density of the site are represented in figure 32 and 33.

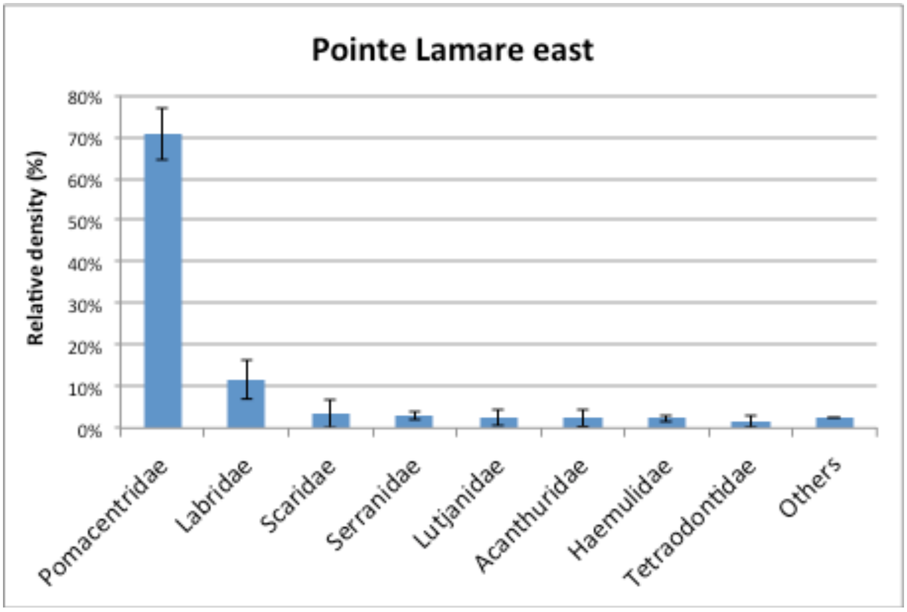


Figure 39. Average density of major fish families (± std error – families under 1% not represented) – Pointe Lamare east.

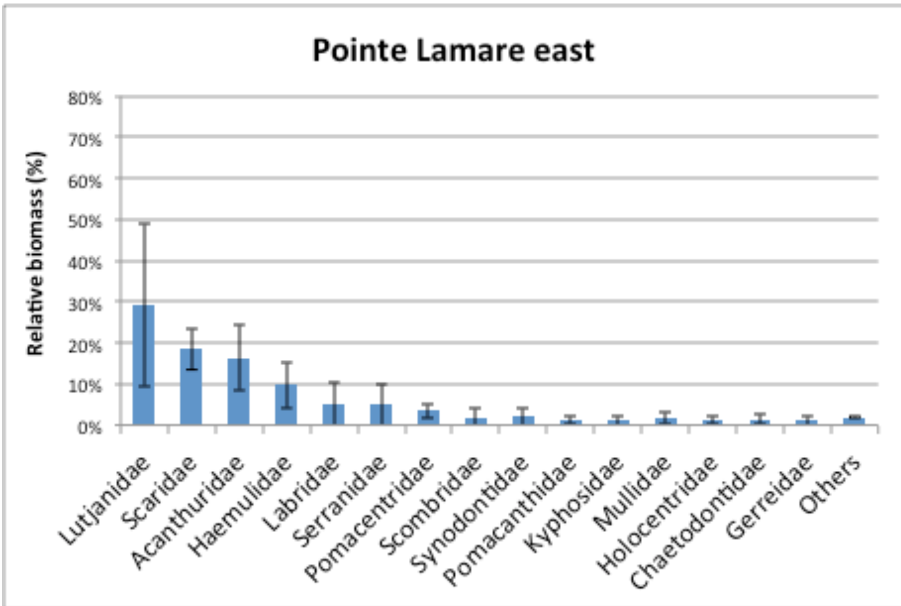


Figure 40. Average biomass of major fish families (± std error – families under 1% not represented) - Pointe Lamare east.

The Pomacentridae dominate the fish populations with an average of 71 ± 7% of the total assemblage. Stegastes partitus and Chromis multilineata are the major species of this family. The Labridae account for 12 ± 5% of the total abundance, second contribution to the assemblage (mainly Thalassoma bifasciatum). The Scaridae and Serranidae each account for 3% of total abundance against 2% for Lutjanidae, Acanthuridae and Haemulidae.

The average biomass value is of 6540 ± 3501 g/200m². The Lutjanidae (29 ± 20%), parrotfish (18 ± 5%) and Acanthuridae (16 ± 8%) contribute to more than half of the total biomass. Only 5 species account for half of the total biomass: Lutjanus griseus (20 ± 22%), Lutjanus mahogoni (8 ± 15%), Sparisoma rubripinne (7 ± 7%), Sparisoma aurofrenatum (8 ± 4%) and Acanthurus bahianus (8 ± 7%). These species have a high commercial value. Strong standard errors on biomass values show that there is a great disparity between transect at the same site.

- Trophic groups

The assemblage is composed of territorial herbivorous fish (44%), planktonivorous (31%) and mobile invertebrates consumers (11%). Despite these high values, they participate only to 1 to 3% of the total biomass. Carnivores account for 33% of the total biomass. Strict herbivores constitute 36% of the biomass but only 6% of total abundance (Figure 34).

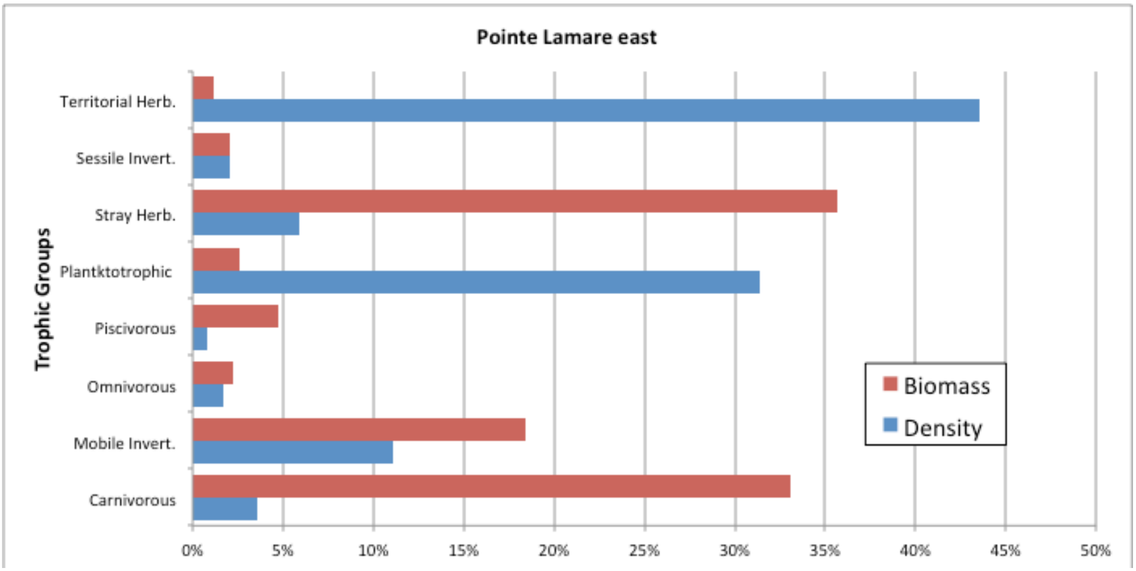


Figure 41. Fish density and biomass per trophic groups – Pointe Lamare east.

3.1.3. Conclusion

3.1.3.1. benthic species

The underwater landscape along the northern Caribbean area of Martinique is composed of basalt flows and volcanic rocky bottoms. Inventories and site description describes a very complex landscape, with vertical drop offs, canyons, deep valleys, offering a wide variety of favorable habitat for the development of underwater life. The nature of the substrates and the hydrodynamics of the sector are, however, not favorable to the installation of coral reefs of the same type as those found in the south of the island, where fringing reefs developed. However, the biological communities reveal an important biodiversity. The non-exhaustive lists bring together organisms of all marine zoological groups. Communities growing on rocks are complex and show a dominance of large sizes sponges, along with sparse colonies of hard corals. La Perle ilet and le Sous-marin north to the village Prêcheur show well-developed coral communities. The endangered elkhorn coral are present in this sector. All the sites have very dense algal populations reflecting an degraded health status for the entire area, even for geographically remote sites not directly subjected to human activities. Siltation is important and reflects chronic hypersedimentation limiting the development of benthic communities, including the site Citadelle, threatened by the Prêcheur river outflow. In the maximum biodiversity zone (10-15 m), assemblages are relatively homogeneous. The species found are the same across the entire area. Coral species are generally small, with the exception of Agaricia colonies that develop on vertical drop offs. There is usually no massive coral in this area. Coral species have limited growth due to the environmental conditions in which they develop, ie strong currents and silt deposition. These conditions are in favour of filter feeders such as sponges and sea fans who need currents for their nutrient intake.
The combination of various habitats and the continuity between ecosystems are favorable to species migration. This system promotes the development of a significant biodiversity. Seagrass beds provide nurseries in this area of steep slopes landscape that are habitats unsuited to the development of juvenile fish. Boulders, crevices, drop offs, caves and

overhangs are contrasting habitats harboring different species. The sandy areas are home to many burrowing species, including small sizes macroinvertebrates (crustaceans, worms, molluscs ...), which are part of the food chain.

3.1.3.2. Fish assemblages

Species richness

158 species belonging to 48 families were identified along the Prêcheur MPA. The most represented families are the Serranidae (19 species), Labridae (15 species), Haemulidae (13 species), parrotfish and Lutjanidae (10 species). These families bring together more than half of the total species identified. Pomacentridae, Carangidae and Holocentridae total respectively 9, 7 and 6 species.
Species richness varies between sites mainly because of habitats' configuration. Drop offs, crevices, massive sponges, and coral communities on rock habitats are criteria that promote high species richness in fish populations. The Citadelle (90 species), Pointe Lamare east (89), Les Basses (84), le Sous-marin (84), Pointe Lamare west (83), Babody north (80), Babody south (81) and La Perle (75) sites have a high ecological interest for fish populations.
Species classified as "Vulnerable" or "Near threatened" on the IUCN Red List were observed at Citadelle, Pointe Lamare east and west, Les Basses, Babody north and south: *Lachnolaimus maximus, Lutjanus analis, Mycetroperca interstitialis, Balistes vetula, Lutjanus cyanopterus, Aetobatus narinari*.

Density and biomass
The average density of fish populations ranges from 476 ± 298 ind / 200m² at Pointe Lamare east to 1226 ± 410 ind / 200m² at La Citadelle. The abundance of fish at Le Sous-marin is 1033 ± 307 ind / 200 m² while that calculated for the site Les Basses is 601 ± 114 ind / 200m². The densities of Babody south and north stations are respectively 564 ± 198 ind / 200 m² and 551 ± 155 ind / 200 m². The differences in density values are explained by the fluctuation of abundance of the two families Pomacentridae and Labridae. These two families account 87% of the total density.
The density values of fisheries targeted species (Parrotfish, Lutjanidae, Serranidae, Mullidae, Acanthuridae), range from a minimum of 27 ± 10 ind / 200m² at Le Sous-marin to a maximum of 63 ± 8 ind / 200m² at Babody north.
Target species at Pointe Lamare east is 4727 ± 2695 g / 200m², and 4304 ± 1507 g / 200m² at La Citadelle.

All sites are dominated by carnivores (planctonophage, 43%) and herbivores (territorial herbivores, 48%). *Chromis multilineata, Thalassoma bifasciatum* represent the two major species of planktivorous fishes. Territorial herbivores are mainly represented by *Stegastes partitus*. Carnivores and herbivores dominate biomass of stray fishes. Among carnivores, three major species are represented: *Ocyurus chrysurus*, *Cephalopholis fulva*, *Lutjanus mahogoni*. *Acanthurus coeruleus*, *Sparisoma aurofrenatum* and *Acanthurus chirurgus* largely contribute to biomass of itinerant herbivores.

Species richness and fish populations' structure according to density, biomass and trophic group assemblage point to four areas of high ecological interest. The area consists of La Perle (2 sites), Le Sous-marin and Les Basses. Further south, La Citadelle has great environmental value. Babody south and north sites have structural complexity and diversity of habitats (seagrass, sand, coral communities on rock) in favour of fish populations development.

3.2. Sint Eustatius Statia National Marine Park

3.2.1. Characterization of the benthic communities of Sint Eustatius, Caribbean Netherlands. Erik H. Meesters, J.P. Maréchal, E Trégarot, E. Dijkman

3.2.1.1. Introduction

Sint Eustatius, English Saint Eustatius, also called Statia, is an island and special municipality within the Kingdom of the Netherlands, in the Lesser Antilles, in the north-eastern Caribbean Sea. It lies about 16 miles (26 km) southeast of Saba and 5 miles (8 km) northwest of the island of St. Kitts. Its capital is Oranjestad (Figure 42).

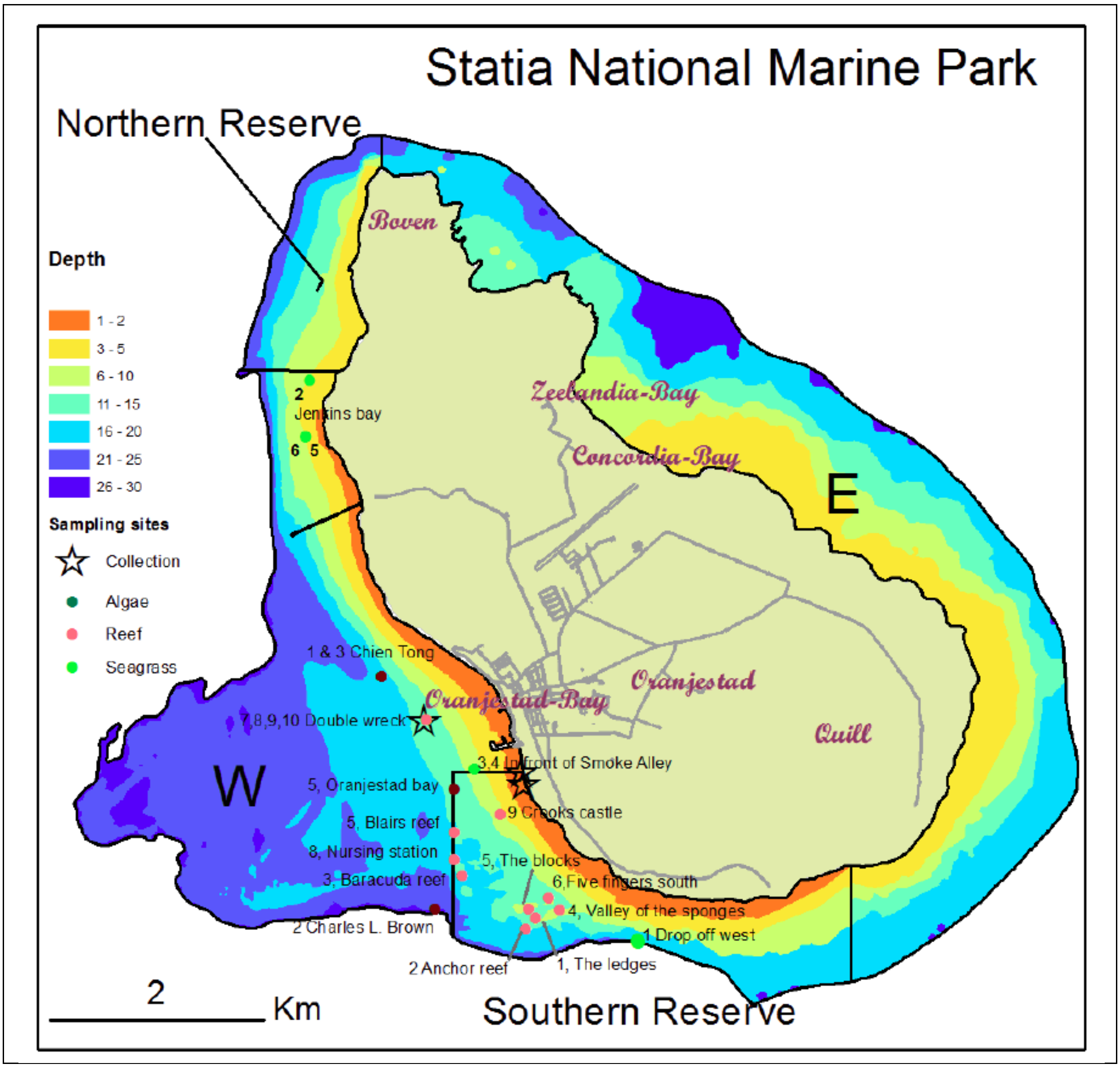


Figure 42. Sint Eustatius. General outline of the island and Marine park.

Sint Eustatius measures 6 miles (10 km) long and up to 3 miles (5 km) wide and, with Saba, forms the north-western termination of the inner volcanic arc of the Lesser Antilles. The island is dominated by two extinct volcanoes, with a flat central plain separating the two. Sint Eustatius is situated in the trade wind belt and receives an average of 44 inches (1,125 mm) of rainfall annually, mainly between May and November, but climatic conditions vary considerably over the island. On the east (Atlantic) side the wind is strong and the vegetation low. On the calm west (Caribbean) side grow tall palms and breadfruit trees and thick banana groves. At White Wall, on the southern slope of one of the volcanoes, The Quill, arid conditions prevail and xerophytic plants (adapted to growth with limited water) predominate. The remainder of the island is covered with tough, thorny bushes and trees, many of which lose their leaves during the dry season

Three National Park areas protect the high biodiversity and unique tropical ecosystems present on both land and sea and the total protected area covers 33km^2 - almost twice the size of the island of St Eustatius. The national parks system was initiated by the Island Government in 1996 to protect diverse habitats on and around the island. The Government delegated management authority for the parks to a local NGO – St Eustatius National Parks Foundation. Numerous endangered or critically endangered species are protected through active research and monitoring programmes, including three species of sea turtles, the Antillean Iguana, Red Bellied Racer Snake, orchids, cacti and the endemic vine 'Statia Morning Glory'.

The Statia National Marine Park was established in 1996 with the objective of conserving and managing the marine resources for the benefit and enjoyment of the people and future generations. The park surrounds the island (encompassing the entire coast) and extends from the high water mark out to a depth of 30 metres (100 ft). The total area of the park is 27.5 km^2. Within the Marine Park, there are two actively managed reserves where anchoring and fishing are not permitted in order to protect pristine coral reef.

Benthic communities of Statia were first derived from satellite data followed by surveys under water in 2008 together with the Dutch Staatsbosbeheer.

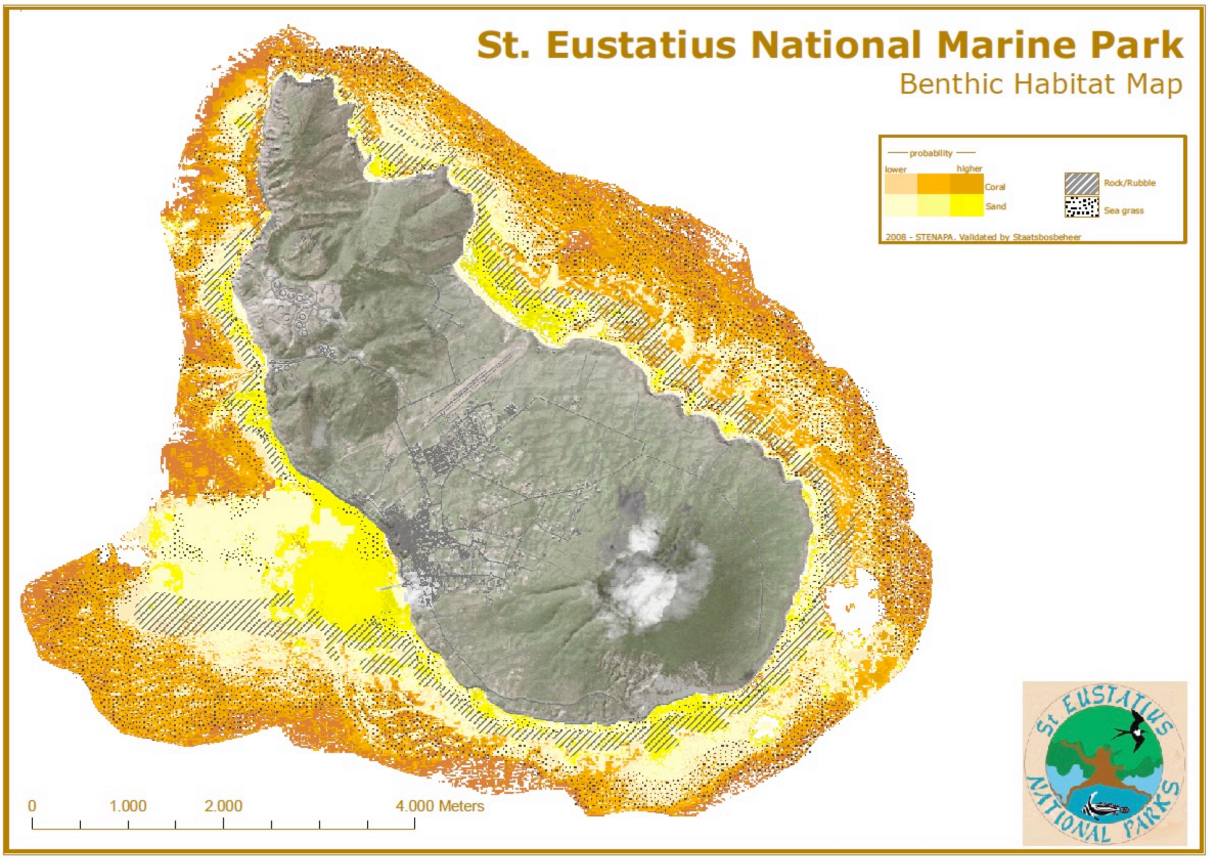


Figure 43. St. Eustatius benthic map as produced by Stenapa and Staatsbosbeheer in 2008.

In 2013 a large number of video drops were taken around the island to gather more information on the distribution of the different benthic communities around the island. This student project resulted in a new map for the Statia benthic communities (Debrot et al. 2014).

3.2.1.2. Ecological diagnostic

3.2.1.2.1. Habitat mapping

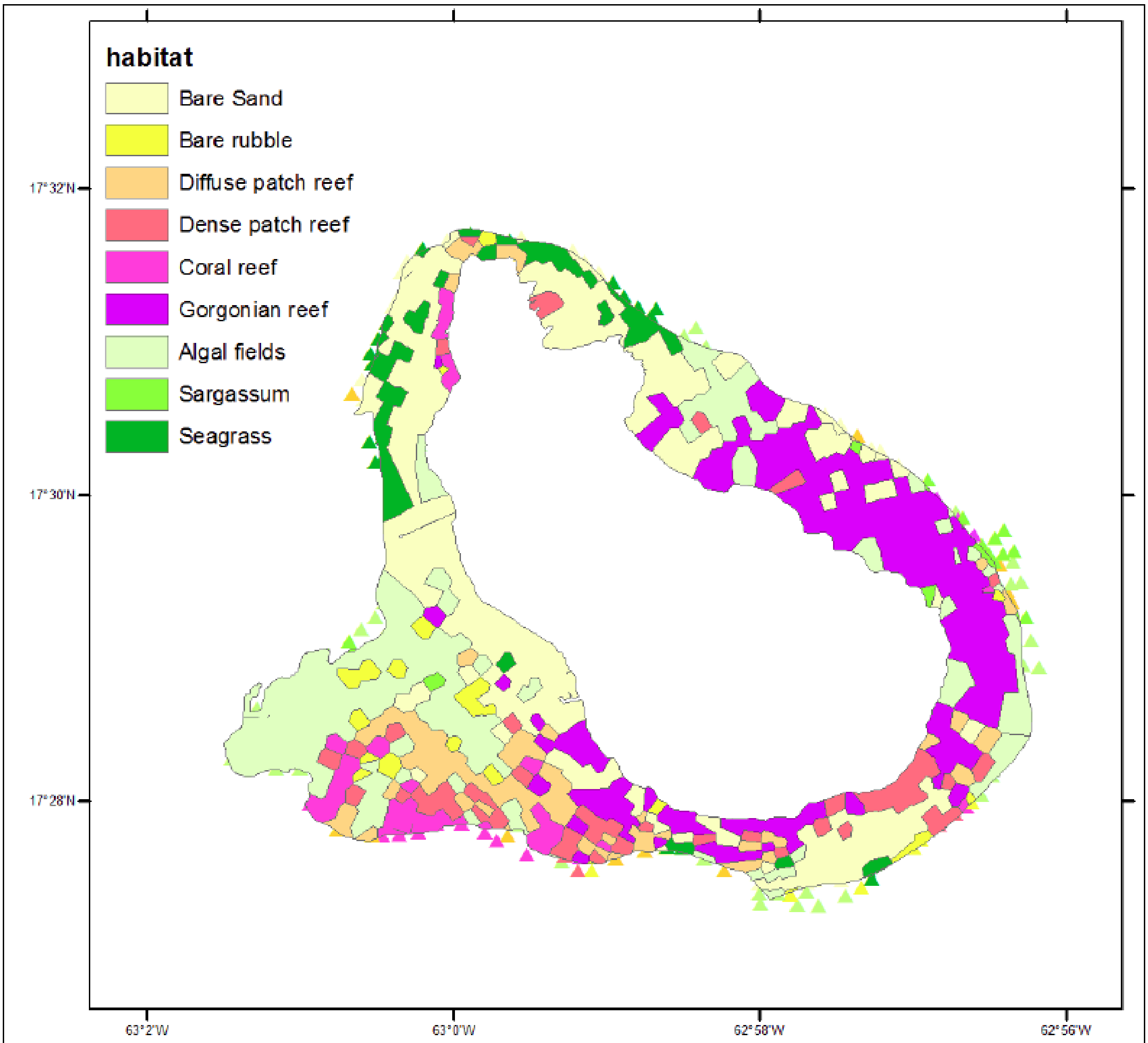


Figure 44. Benthic map according to Debrot et al. 2014.

Videos surveys from 2013 were reassessed for the benthic composition of several categories to improve the existing benthic map.

3.2.1.2.2. Methods and results

810 Video drops around Sint Eustatius were analysed. From each video we assessed the cover of the living components and the main bottom characteristics. We assessed hard

corals, soft corals, sponges, seagrass, macro-algae and zoanthids as they could be distinguished from the videos. Furthermore, we identified the amount of hard bottom, rubble, and sand. All categories were assessed into three cover categories: less than 10%, between 10 and 50%, and more than 50%. All data were recorded into a spreadsheet which was subsequently further analysed using multivariate analyses. Site data were split into living components and bottom components.

The data on the biota was first analysed to see if there were sites that had no cover by living flora or fauna. Of the 810 sites, 269 had no living cover. Consequently the data set was reduced to 541 sites (i.e. video drops). These were compared by calculating a distance matrix using Euclidean distance and further analysed by non-Metric multiDimensional Scaling (Kruskal 1964a, b), cluster analysis (Legendre and Legendre 1998), and gradient analysis (Oksanen et al. 2015).

With nMDS environmental gradients can be detected. **Figure 45** shows important gradients in the data. Each point represents the biological composition at one location and the closer points are in the plot, the more similar they are. On the left side gradients in the living components are superimposed on the ordination. They show in what direction positive gradients exist in the ordination of the samples. For example, moving more to the bottom area of the plot, the locations become more dominated by seagrass. On the right side we have included gradients in the underlying bottom and depth. So moving to right side of the plot, the sites are generally deeper; moving up sites tend to become more on hard bottom, and down more sandy. When the bottom characteristics and depth were examined it became clear that algae were more dominant in the deeper parts. Sea grass and sand were correlated and sponges and soft corals were more present in the shallower parts of the island's marine park.

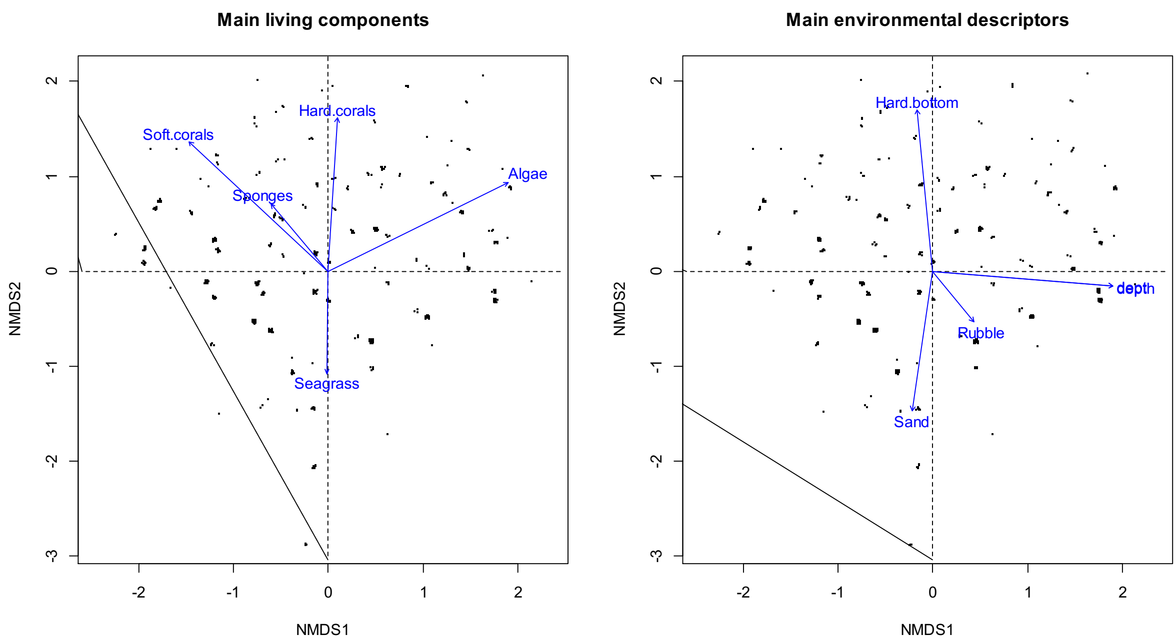


Figure 45. nMDS with vectors indicating the direction of positive correlation with biota (left), and with bottom characteristics and depth (right). Many sites have equal values and are plotted on top of each other. Therefore some jittering was added to show where there

are multiple sites in the nMDS. Black dots are sites and the closer they are the more similar their composition.

The clustering indicated that there was a clear separation of the living biota into 5 groups which are to a large extent characterized by dominance of either macro algae, hard corals, soft corals and sponges, or sea grass. The 5 clusters can be visualized in the nMDS ordination plot (**Figure 46**). From this plot one can see how the clusters are positioned in 2-dimensioal ordination space. If this plot is combined with those in **Figure 45**, we would expect that cluster 4 is mostly dominated by sand and seagrass. Cluster 5 should have generally more hard corals, and cluster 1 more soft corals. We investigated the average composition of the 5 clusters and these results are shown in **Figure 47**. Combining the results of **Figure 46** and **Figure 47** it is clear that there changes are less sudden than suggested by the pie charts in **Figure 47**. There are sites in clusters 3 and 1 that have some coral cover and vice versa are there sites in cluster 5 that have some soft corals or macroalgae.

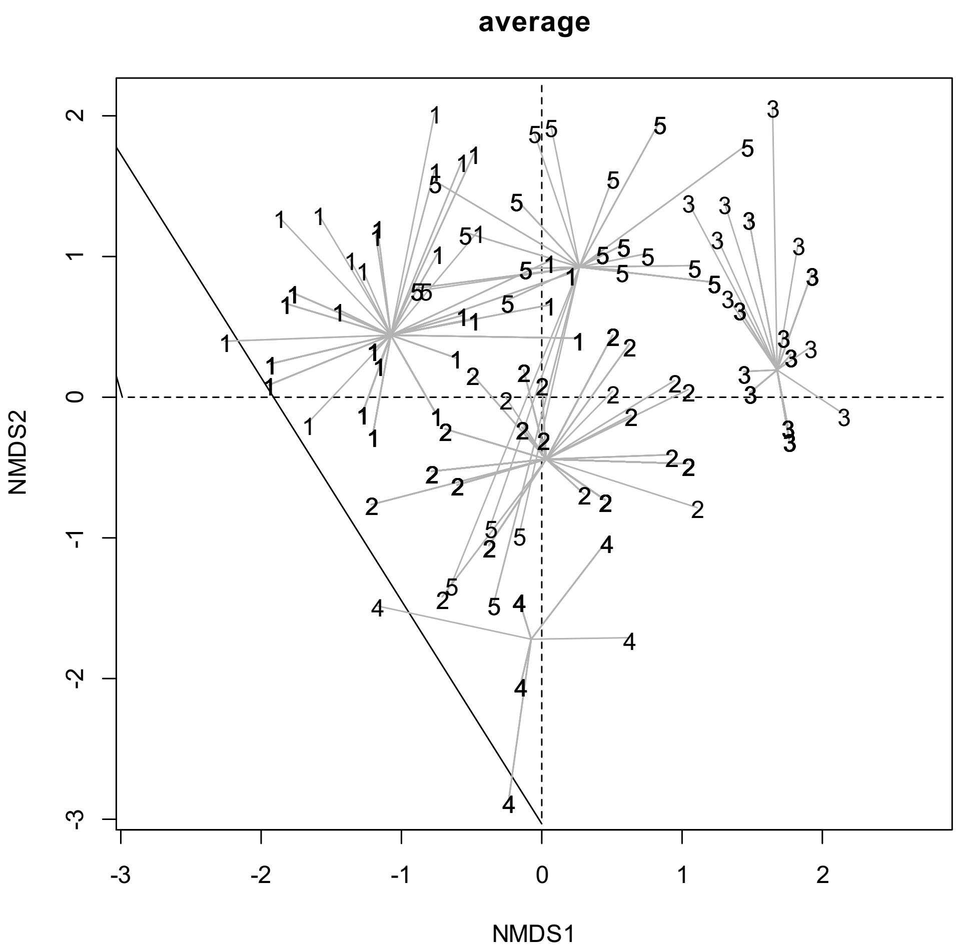


Figure 46. nMDS with the 5 clusters that were detected (using hierarchical clustering and average linkage). Here overlapping sites are not shown to prevent the plot from becoming too cluttered.

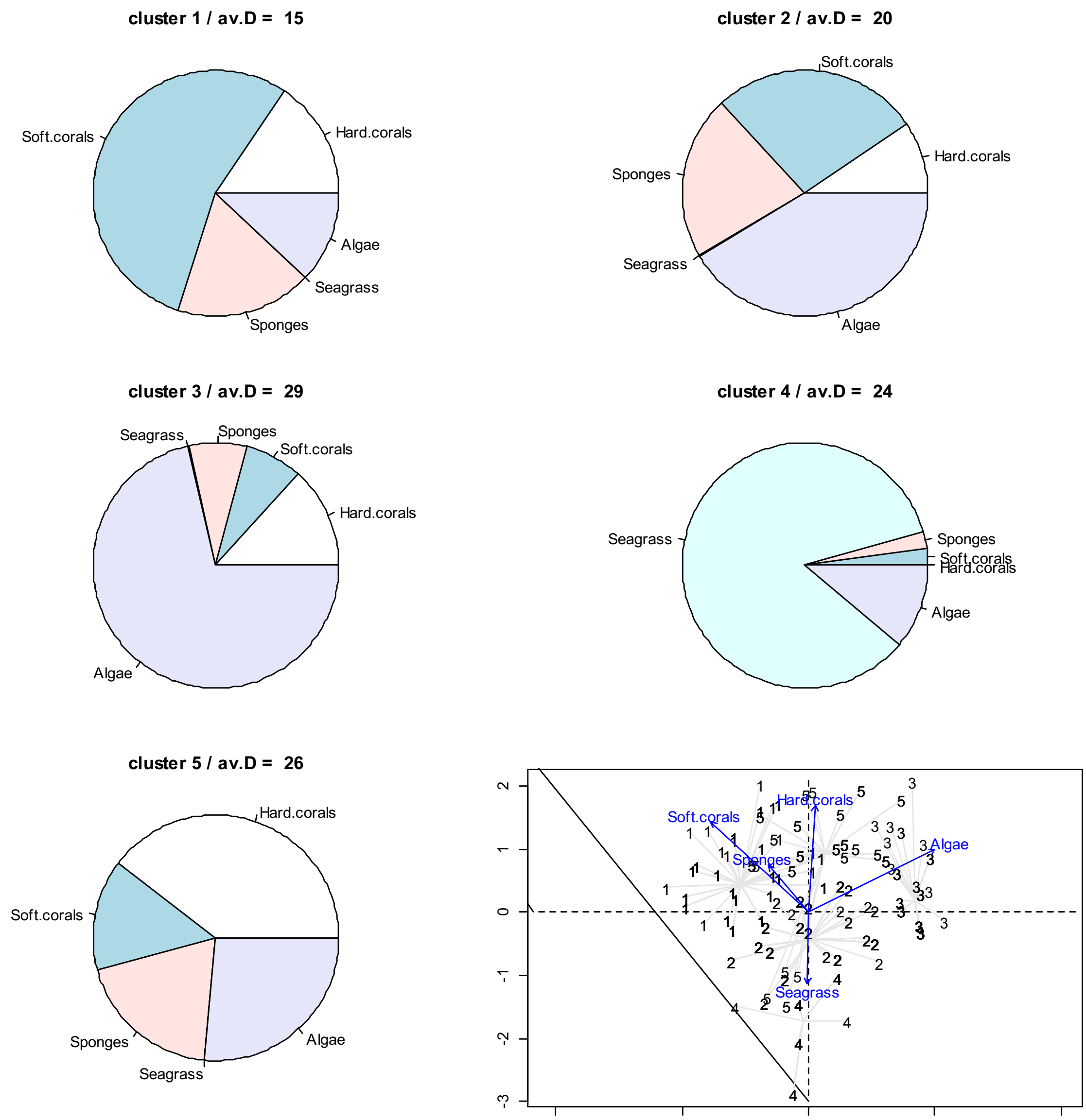


Figure 47. Characterization of the different clusters. The pie charts give the relative contribution of the distinguished bottom categories. The last plot gives the 2 dimensional ordination plot from the nMDS analysis and the vectors of change for the biotic components as well as the 5 clusters.

There were also a number of videos that did not show any living organisms. Those were categorized into the bottom components only. Clustering showed that there were basically four groups, one consisting solely out of sand (176 sites), one being mainly rubble (3 sites), one a combination of rubble and sand (7), and one site which was a mix of rubble and hard bottom. All the categories are shown in Figure 48.

Figure 48. Map of bottom communities of St. Eustatius. Numbers one to five are the clusters from Figure 47. Numbers six to seven are the sites were cover by living organisms was zero, they are respectively sites where only sand was detected (number 6), only rubble (7), a mix of sand and rubble (8), and one site (9) with a mix of rubble and hard bottom.

Based on the clustering a new benthic map was created by ED (Figure 49). In this map the habitats are named after the dominant substrate cover. For example the Soft corals group is dominated by soft corals covering approximately 60% of the bottom and was named cluster 1 in figures 46, 47 and 48. Previous maps have interpolated data here, but it was decided that the distance over which interpolation would be needed is too much to predict reliably the habitat.

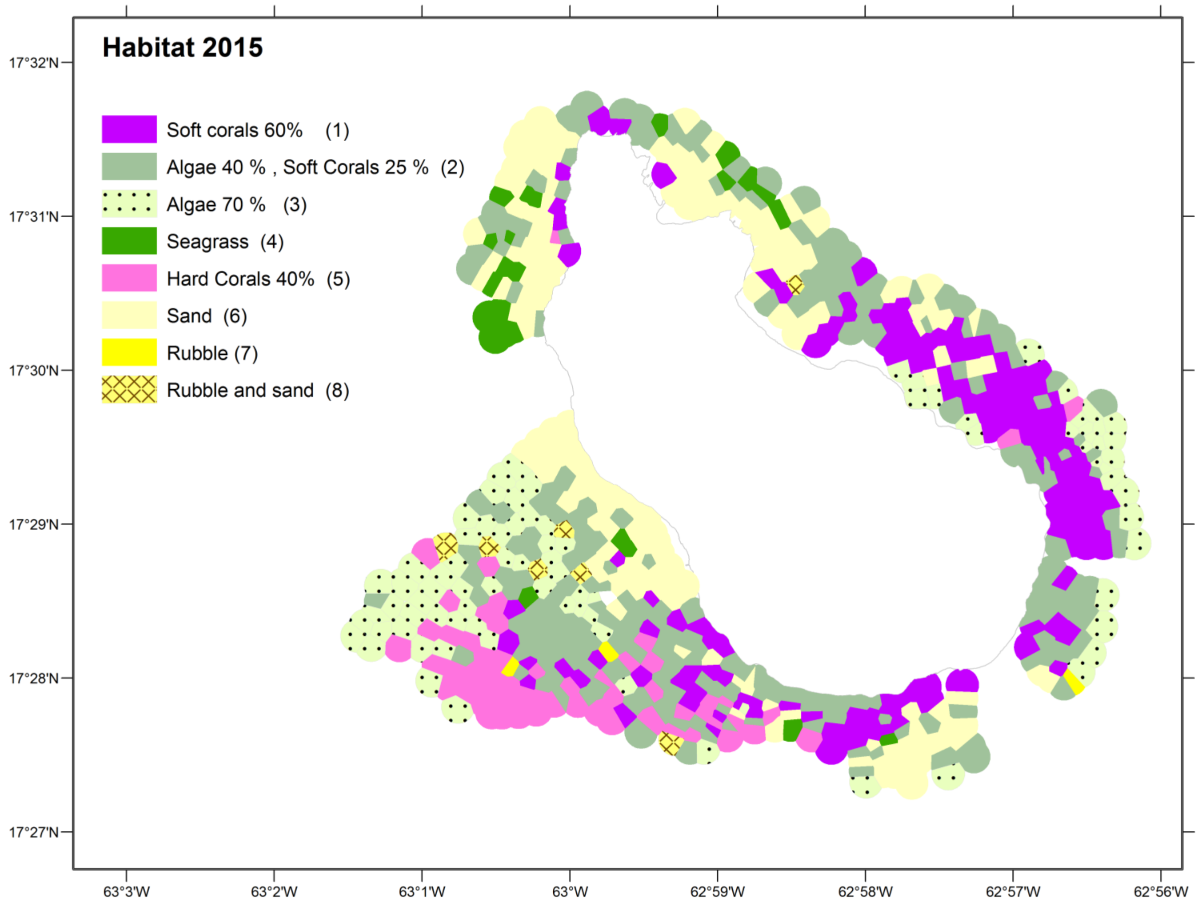


Figure 49. Habitat map for St. Eustatius. Video data were lacking for the area around the NUSTAR terminal.

3.2.1.2.3. Overview of sites benthic cover in and outside Statia National Marine Park.

	Transect		
Site	T1	T2	T3
S1	10	10	10
S10	10	10	10
S11	10	10	10
S12	10	10	10
S13	10	10	10
S14	10	10	10
S15	10	10	10
S16	10	10	10
S17	10	10	0
S2	10	10	10
S3	10	10	10
S4	10	10	10
S5	10	10	10
S6	10	10	10
S7	10	10	10
S8	10	10	10
S9	10	10	10

Sites	Park	Depths
S1	in	20.0
S4	in	15.0
S6	in	19.7
S7	in	20.0
S8	in	14.4
S10	in	13.0
S12	in	15.0
S13	in	16.5
S14	in	18.0
S16	in	12.0
S17	in	22.0
S2	out	18.0
S3	out	23.0
S5	out	22.0
S9	out	23.0
S11	out	24.0
S15	out	25.0

Location of sites in or outside the park and average depth per site.

The benthic community in St. Eustatius is primarily one that is dominated by macroalgae (Figure 50). Cyanobacteria are nowadays also an important component. This indicates that there has been a phase shift from communities dominated by corals and crustose coralline algae to one dominated by macroalgae and cyanobacteria.

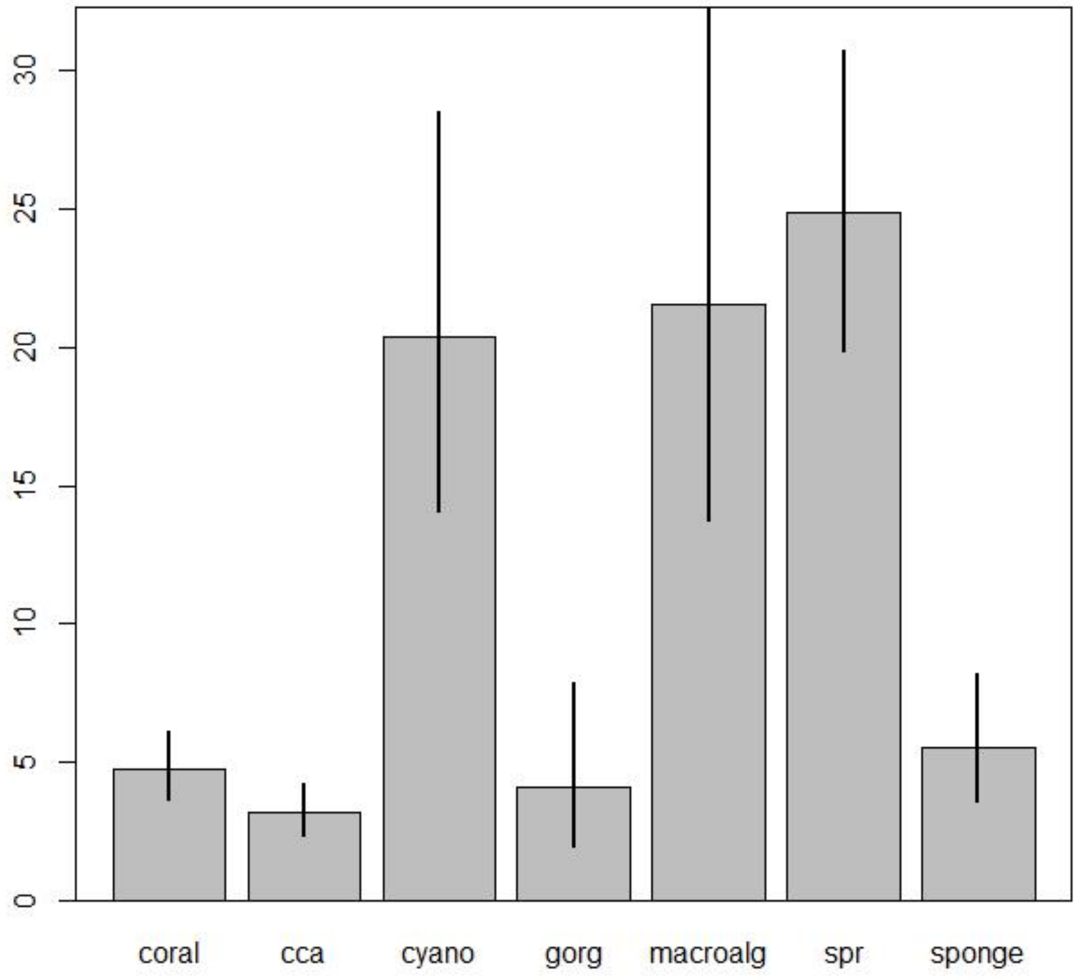


Figure 50. Mean percentage cover per site for main benthic categories including 95% confidence limits. Abbreviations under bars: CCA, crustose coralline algae; cyano, cyanobacteria; gorg, gorgonians; macroalg, macro algae; spr, substrate-pavement-rubble; sponge, sponges.

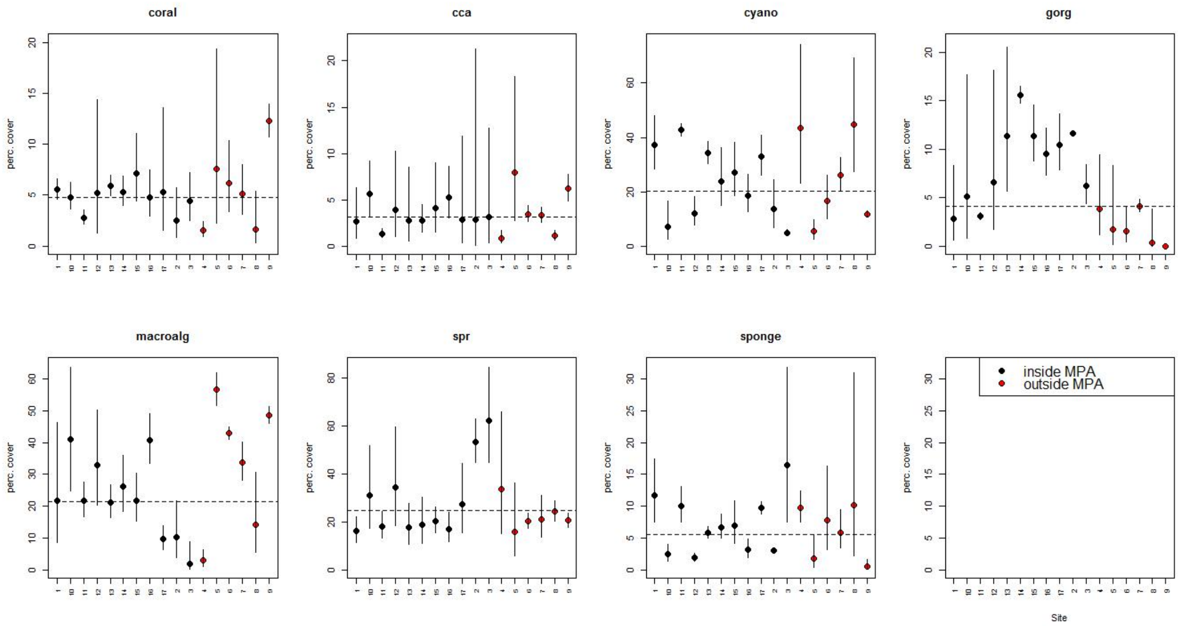


Figure 51. Percentage cover of the most important benthic categories on the different sites. Black symbols are inside the marine park, red circles are outside the MPA. CCA, crustose coralline algae; cyano, cyanobacteria; gorg, gorgones; macroalg, macro algae; spr, substrate-pavement-rubble; sponges, sponges. Labels on the x-axis are site numbers. Vertical bars denote 95% confidence limits. Overall mean given by dashed line. Note different scales on the y axes.

Statistical analyses (mixed modelling of each benthic category) indicate that there is no difference between categories inside and outside of the marine park ($p > 0.4$ for all categories), except for gorgones ($p = 0.002$) (Figure 51, 52). Gorgones are restricted to shallow water and inside the park is generally somewhat shallower than outside the park.

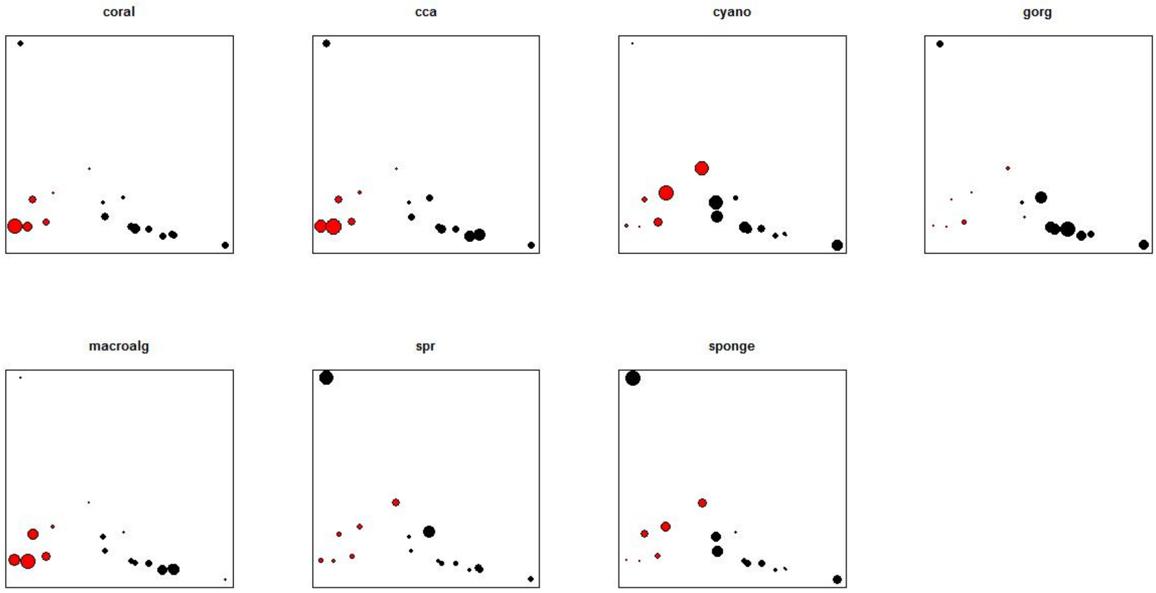


Figure 52. Percentage cover (relative size of symbols) of each category at the different locations. Larger symbols mean higher values. For gorgones it is clear that the values are lower outside of the MPA. Abbreviations and colors as in previous figure. Axes are longitude and latitude.

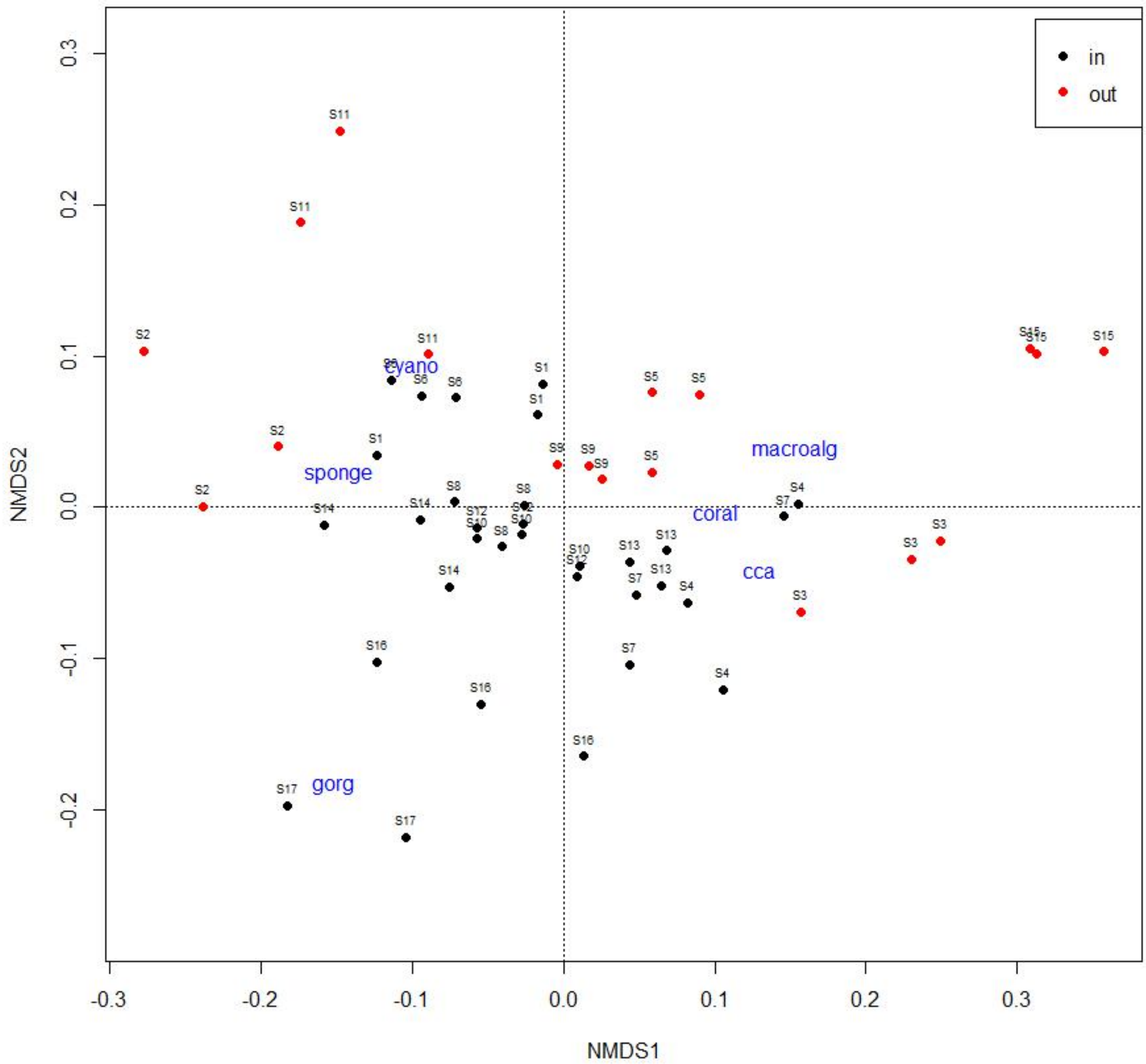


Figure 53. Non-metric Dimensional Scaling plot of categories. Data were 4th root transformed. Each point relates to the composition of the community with respect to the 6 main bottom components in each transect. Points closer to each other are more similar. Each site has 3 transects (except S17 which has 2). Blue text indicates that direction in which the categories have the largest correlations.

Permanova tests indicate that there is a significant difference between sites in the park and outside of the park ($p = 0.005$), but this is mainly due to the presence of gorgones on sites within the park, which are somewhat shallower. Actually, when the same test is carried out without gorgones, the p value becomes non-significant ($p = 0.97$). Sites outside the MPA are on average 6m deeper ($p < 0.001$). Basically, this means that there is no effect of the being in an MPA for the composition of the sites. The only effect that was found was related to the depth distribution of the different sites, showing that shallower sites (more abundant within the MPA) have more gorgones.
The placement of the different categories becomes clearer if we look at a pairs plot (Figure 54).

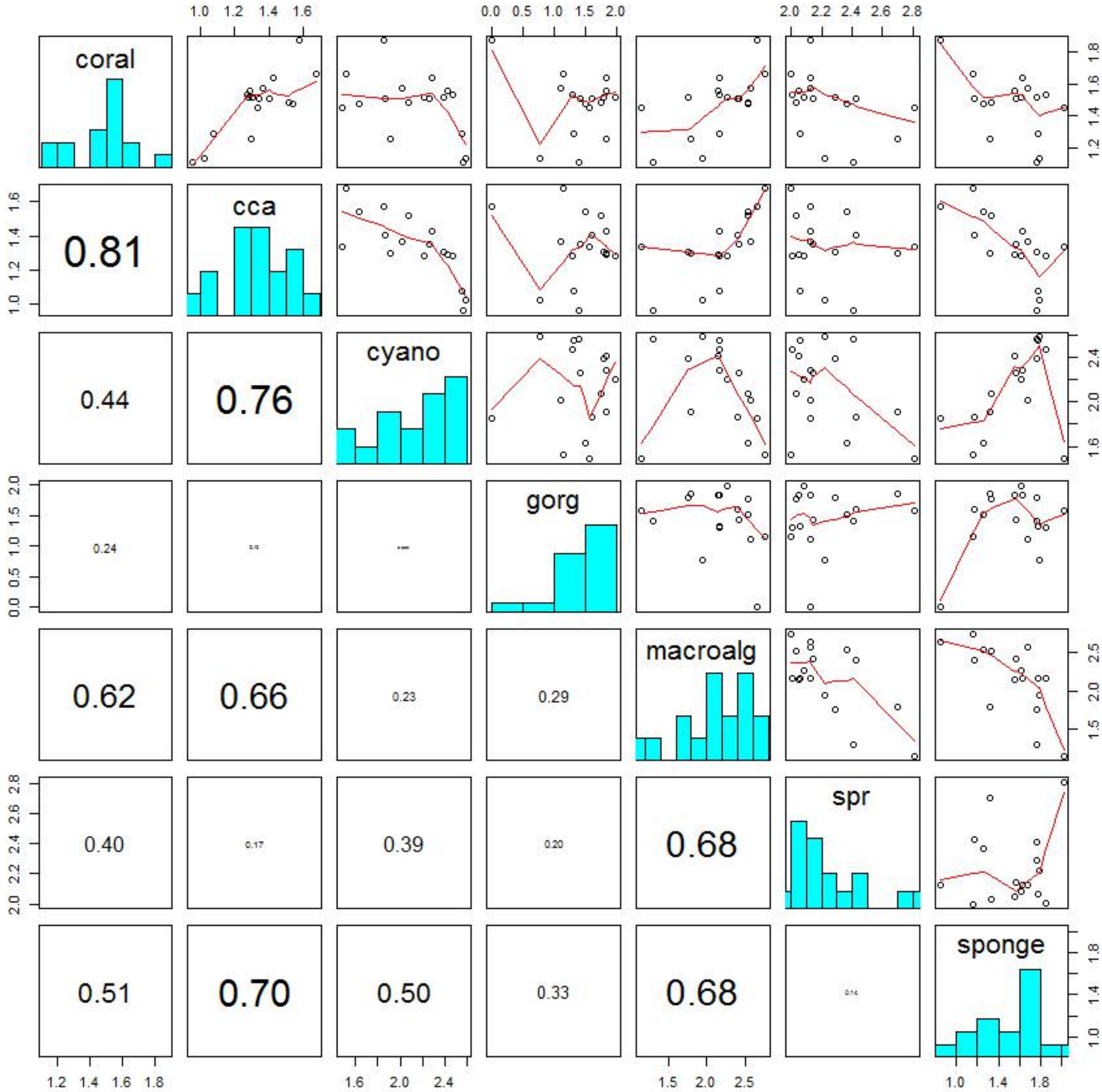


Figure 54. Pairs plot of the different categories based on the mean values per site. In the diagonal there is a histogram of the data, on the lower diagonal the correlations between the different variables and on the upper diagonal the actual data including a non-linear relationship.

There are some high correlations between corals and crustose coralline algae (0.81) and a negative correlation between cca and cyanobacteria (-0.76).

In terms of the composition of the benthic communities within and outside of the MPA there are no differences with the exception of the presence of gorgones. The community is generally dominated by macroalgae and cyanobacteria, both can be as high as 60%. Calcifying organisms as corals and cca cover only a small percentage of the bottom.

3.2.1.2.4. Acknowledgment

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