Mangrove soils: Who drives their recycling functions?

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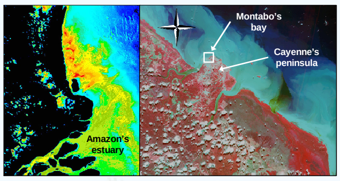
Introduction

The **Amazon River** is responsible of a **huge discharge of sediments** in Atlantic Ocean. A portion of 10 to 20 % of this suspended particulate matter is diverted and follows a north-western path **under the influence of Guiana Current** that results in **a spectacular migration of 1 600 km** of subtidal mud belt along the coastline of Guianas to the Orinoco Delta. In the intertidal zone, mud banks **form extensive mud flats** whose periodic dewatering by tide cycles progressively generates the stabilization of the upper intertidal part. Its **colonization by biofilms** and **then by propagules** imported from fringing mature mangroves, promotes **extending of mangrove ecosystem**.



Plume of suspended particulate matter from Amazon's estuary (left) and its north-western migration along the coastline of French Guiana (right)

In such environment, **highly constrained by a rapid** and **intensive hydro-sedimentary dynamic**, the successional dynamic of mangrove ecosystem gradually leads to the **development of vegetation stage series**, from pioneers to matures and sometimes to senescents. The interactions between sediment, organic matter (OM), aboveground vegetation and meio- and macro-fauna are responsible of **changes in ground characteristics** and **pore-water composition**. These are **related to microbial community functioning** which is a central component of **biogeochemical processes** and **nutrient dynamics** that take place in mangrove ecosystem.


Early colonization stage by micro-phytobenthos and mangrove of the upper intertidal part of mud flat (Montabo's bay, january 2006)


Rapid and intensive erosion phase of mangrove (Montabo's bay, april 2011)

Objectives

Our objectives were to understand **which environmental factors** were the **main drivers of the expression of microbial functions** in these intertidal sediments. With this aim, we distinguished several classes of environmental factors potentially involved in regulation of microbial functions:

- **Mangrove evolutionary stages** defined by 3 facies, *i.e.* **pioneer** (P, <1y), **coppice** (C, <5y) and **young forest** (F, <10y);
- **Hydro-climatic conditions**, *i.e.* two contrasted seasons: **wet** (WS) and **dry** (DS);
- **Hydro-** and **pedochemical properties** of soils, including qualitative characterization of **soil OM** (SOM) by SS ^{13}C CP-MAS NMR spectroscopy;
- **Rhizospheric effects**.

Functions of microbial communities investigated were:

- **Microbial respiration** (MR, Oxitop®);
- **Potential catabolic richness** and **diversity** by community level physiological profiling (CLPP, Biolog EcoPlates™);
- **Activity of 6 enzymes** involved in CNPS biogeochemical cycles.

Types of soils investigated were:

- Within P facies (3): a non-rhizospheric soil (NRZ), rhizospheric soils of *Avicennia* (RZA) and *Laguncularia* (RZL);
- C facies (1): an undifferentiated rhizospheric soil (RZ);
- F facies (1): RZ soil.

Study site

The study site is **a fringing mangrove** containing a mixed-species assemblage of ***Avicennia germinans*** and ***Laguncularia racemosa*** located in urban context in **French Guiana** (Montabo's bay, Cayenne). This mangrove results from a massive arrival of silt, which has begun to deposite since 2003, where **3 main facies occur** corresponding to **vegetation evolutionary stages**.

Mangrove structure and plot characteristics

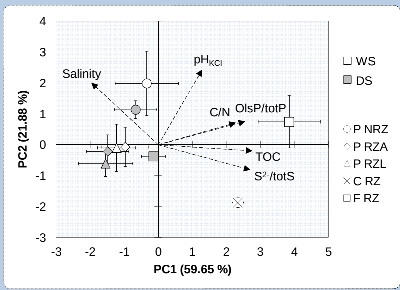
Characteristics			Facies P	Facies C	Facies F
Tree density		Nb / ha	$1.2 \times 10^6 \pm 0.8$	$5.8 \times 10^4 \pm 0.4$	$11.4 \times 10^3 \pm 0.6$
Living trees	*Avicennia*	%	35 ± 10	56 ± 7	81 ± 8
	Laguncularia	%	65 ± 10	44 ± 7	18 ± 8
Dead standing trees		%	0	12 ± 8	30 ± 7
IVI	*Avicennia*		102	105	162
	Laguncularia		98	95	38
Level relative to tidal position			Low	Medium	High
Mangrove debris deposit			None	Wood	Leaf litter, wood
Extent of mangrove rhizosphere			Very low (seedling)	Extent of near-surface-roots	Large extent of near-surface roots and pneumatophores

Values are means (n = 3) standard deviations. *IVI*: Importance Value Index (Curtis & McIntosh, 1950)

As succession proceeds…

- Huge **decrease of tree density** with important **increase of mortality**;
- Strong competition: ***Avicennia* overtopped** and **gradually excluded *Laguncularia***;
- **Ground elevation** and **distance**, respectively relative to tidal position and shoreline;
- **Increase of mangrove biomass inputs** to sediment and **rhizosphere extent**.

Hydro-pedochemical properties of soils



Biplot of PCA of hydro-pedochemical properties of soils
Symbols depict means (n = 5) with standard deviations (in brackets) on PC1 and PC2
Vector scale: x3; C/N: molar C/N ratio; OlsP: Olsen phosphorus; totP: total phosphorus; TOC: total organic carbon; S^{2-}: sulphide; totS: total sulphur

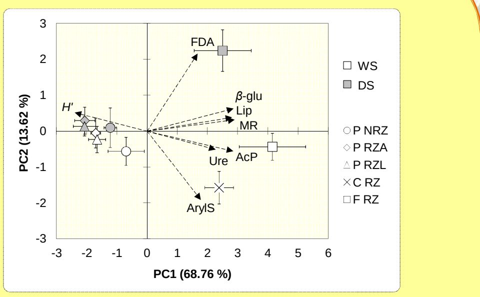
Spatial and seasonal variations

- **SOM enrichment** as succession proceeds;
- **Complex salinity and nutrient fluctuations** due to: hydro-climatic variation, micro-topography, ocean-distance, vegetation cover and evapotranspiration, redox status (S^{2-});
- **C/N ratio** around 10 are **representative of marine and micro-phytobenthos derived OM** (Marchand et al., 2003; Debenay et al., 2007);
- Progressive enrichment of soils in alkyl C and carbohydrate C indicated an **increased influence of mangrove inputs on SOM quality**.

			Molar C/N	TOC content ($g.kg^{-1}$ DW)				Humification index
			Ratio	Total	As alkyl C	As carbohydrate C	As acid-soluble fraction	Ratio
WS	P	NRZ	11.9 ± 1.4 ^{ab}	14.7 ± 3.5 ^{b}	2.7	2.9	4.5	0.6
		RZA	10.4 ± 0.7 ^{b}	13.5 ± 1.5 ^{b}	3.8	2.4	2.9	1.0
		RZL	10.4 ± 0.8 ^{b}	12.9 ± 1.7 ^{b}	2.7	2.8	3.5	0.6
	C	RZ	11.9 ± 0.5 ^{ab}	19.9 ± 1.0 ^{a}	4.8	3.2	5.2	0.9
	F	RZ	12.0 ± 0.4 ^{a}	22.8 ± 1.6 ^{a}	6.9	4.8	4.2	1.0
DS	P	NRZ	10.4 ± 1.0 ^{ab}	13.7 ± 1.7 ^{b}	3.4	2.7	3.6	0.9
		RZA	9.4 ± 0.8 ^{b}	12.3 ± 1.4 ^{b}	2.8	2.6	3.1	0.7
		RZL	9.6 ± 1.1 ^{ab}	13.3 ± 2.4 ^{b}	3.0	2.8	2.7	0.6
	F	RZ	11.1 ± 0.3 ^{a}	19.0 ± 1.5 ^{a}	6.1	3.8	3.6	1.1

Values are means (n = 5) standard deviations or are based on a composite sample. For each season, values followed by the same letters in a column do not differ significantly from each other at $P < 0.05$ (one-way ANOVA, test of multiple comparisons of Tukey). Humification index: Alkyl C to *O*-alkyl C ratio

Functional patterns of microbial communities

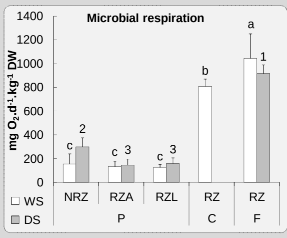


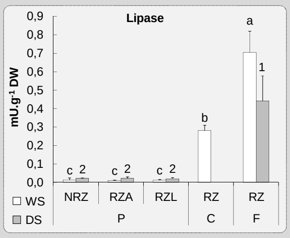
Biplot of PCA of enzyme and catabolic activities, and functional diversities of soils
Symbols depict means (n = 5) with standard deviations (in brackets) on PC1 and PC2
Vector scale: x3; *H'*: Shannon's diversity index; MR: microbial respiration; FDA: fluorescein diacetate hydrolase; *β*-glu: *β*-glucosidase; Lip: lipase; AcP: acid phosphomonoesterase; Ure: urease; ArylS: arylsulphatase

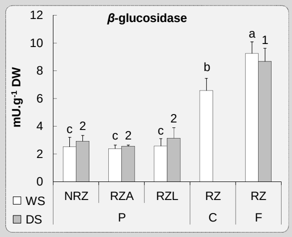
As succession proceeds…

- **Enzyme activities** and **microbial respiration** are **higher**;
- **Functional diversity** shows an **inverse pattern than enzymes**;
- **No significant rhizospheric effect** on functional patterns of P facies soils;
- **Functional patterns are maintained** between the **2 hydro-climatic seasons**.

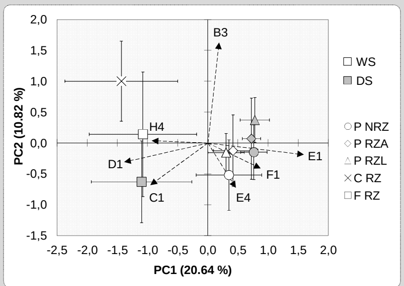
Microbial function expression in relation with SOM







Microbial respiration and lipase and *β*-glucosidase activities of soils
Bars depict means (n = 5) with standard deviations (in brackets). For each season, bars within a graph followed by the same letters or numbers do not differ significantly from each other at $P < 0.05$ (one-way ANOVA, test of multiple comparisons of Tukey). U: µmole hydrolyzed substrate.min^{-1}



Biplot of PCA of catabolic profiles of soils performed on 27 substrates
Symbols depict means (WS: n = 10, DS: n = 15) with standard deviations (in brackets) on PC1 and PC2
Vector scale: x3; only the most driving variables are depicted; B3: *D*-galacturonic acid; C1: tween 40; D1: tween 80; E1: *α*-cyclodextrin; E4: *L*-threonine; F1: glycogen; H4: putrescine

		MR	Lipase	*β*-glucosidase
TOC	WS	r = 0.921 ***	-	-
	DS	r = 0.860 ***	-	-
TOC as alkyl C	WS	-	r = 0.947 ***	-
	DS	-	r = 0.936 ***	-
TOC as carbohydrate C	WS	-	-	r = 0.902 ***
	DS	-	-	r = 0.973 ***

Pearson's correlation coefficients (r). *** depicts a significance level of $P < 0.001$

As succession proceeds…

- Strong increase of **microbial respiration in relation with TOC enrichment**;
- **Higher increases** are those of **lipase** and ***β*-glucosidase activities**, which **are highly correlated with** increased availability of their respective natural substrates, *i.e.* **plant lipids** and **carbohydrates** (*e.g.* cellulose, wax, cutin);
- PCA map of CLPPs exhibits a **functional specialization** of microbial communities toward some C sources, *i.e.* **methylenic structures *vs* forest community** and **carbohydrate polymers *vs* pioneer community**.

Conclusion

In **pioneer stages**, the microbial communities are fuelled and controlled by **low contents** and **poor quality of soil TOC**. Thus, they show **low activities** and are constrained to diversify their C-acquisition mechanisms resulting in **high functional diversities**. **As mangrove succession proceeds inward**, a **TOC enrichment** occurs which results in **higher microbial activities**. Concomitantly, an **increased imprint of mangrove vegetation on SOM quality** is revealed. These **differences in organic sources** and **qualities** lead to **functional loss** and **specialization** of **rhizospheric microbial communities** and subsequently, evidence an **enhancement of above-belowground functional linkages**.

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