AMAPhD

24 Novembre 2023

Organisateurs :

Vincyane Badouard, Alexandre De Haldat Du Lys, Colin Prieur

Planning AMAPHD 2023

Café 08h30-9h00					
Accueil	9h00	20	Comité	Welcome	
			Raphaël Pélissier	Mot d'ouverture	
Session 1	9h20	20	Vincyane Badouard	Environmental determinants of the spatial distribution of trees during their ontogeny in tropical forests	
	9h40	20	Gian Luca Spadoni	Fires in socio-ecological systems: tropical and subtropical ecosystems	visio
	10h00	10	Margaux Rojat	Biotic interactions between alien plants and threatened trees endemic to the Mascarene islands	visio
	10h10	15	Yannick Brohard	Point partage des données	
Pause café 10h25-10h40					
Session 2	10h40	20	Guillaume Papuga	MCE (mention complémentaire d'enseignement)	
	11h00	15	Artemis Anest	Trace the evolutionary history of plant forms and functions	
	11h15	10	Iva Visnakova	Lauraceae's structural diversity and evolution.	
	11h25	20	Lydie Messado	Pollination systems, floral scent specificity and overall floral trait diversity in natural orchid communities in Cameroon.	
Déjeuner 11h45-13h20					
Session 3	13h20	20	Simon Tegs	Mathematical modeling and analysis of spatio-temporal models dedicated to tree-grass dynamics in humid savannas.	visio
	13h40	20	Colin Prieur	Exploring sources of instability in the spectral reflectance of a tropical canopy in French Guiana.	
	14h00	20	Yuchen Bai	Leaf/wood discrimination in ULS LiDAR using neural networks	
	14h20	20	Cesar LeBlanc	Predicting future biodiversity trajectories using artificial intelligence	
	14h40	10	Adrien Staquet	Climatic, oceanic and sedimentary conditions of natural renewal of mangroves in French Guiana for an adaptive coastal protection strategy	visio
	14h50	10	Lucie Bivaud	Is global warming blowing hot or cold on high mountain plants? Reduced snow cover, nursery plants and adaptations to cold in temperate and tropical latitudes.	
	15h00	20	Alexandre de Haldat du Lys	Root-stem interactions in trees under climate change. Applications for ornamental tree nursery production.	
	15h20	10		AMAParole	
Pause café 15h30-15h45					
Session 4	15h45	10	Junliu Yang	The use of multitemporal lidar to monitor the impact of climate change on tropical forest C sink	
	15h55	20	Florian Mezerette	Modelling of soil carbon dynamics in temperate forest ecosystems	
	16h15	20	Paul-Emile Augusseau	Analysis of sea-mangrove coastline fluctuations for coastal vulnerability and carbon sequestration assessments. Multi-scale and multi-decadal modeling approach of the influence of hydro-sedimentary and climatic processes in French Guiana.	visio
	16h35	10	Marc Hetier	Impact of anthropization on vector community dynamics: modeling, analysis and simulation. Control of epidemiological risk in peri-forest context in Cameroon.	
	16h45	10	Chloé Mouillac	Impact of harvesting on the dynamics of wild plant populations	
Pizzas 19h					

Table des matières

Mot de la direction

AMAPhD, la journée des doctorants et post-doctorants de l'UMR AMAP, est toujours un moment important de la vie de l'unité. Elle permet de faire un peu mieux connaissance avec les nouvelles têtes arrivées dans l'unité à l'occasion de la rentrée universitaire et d'avoir un panorama complet de l'avancement des projets qui sont, par définition, à la pointe des recherches menées dans les trois axes thématiques de l'unité : Biodiversité (Systématique, biogéo-graphie, écologie), Biomasse (dynamique et production des plantes et des peuplements) et Plantes Numériques (Modèles, analyses et données de l'organe aux écosystèmes). C'est aussi un moment de convivialité entre doctorants, post-doctorants et chercheurs en poste, qui prennent pour l'occasion le temps de relever le nez du guidon pour découvrir les travaux de leurs jeunes collègues. Merci à l'équipe qui a cette année contribué à perpétuer la tradition des AMAPhD, en particulier Colin, Vincyane et Alexandre.

La Direction d'Unité
Raphaël PELISSIER

Environmental determinants of the spatial distribution of trees during their ontogeny in tropical forests.

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Keywords : Tropical forests, Ecological niche, Environmental filters, Community assembly, Micro-environment, Ontogeny, LiDAR

Tropical forests harbour the highest levels of biodiversity in the world. This high diversity is made possible by the coexistence of species, and is partly due to the high habitat heterogeneity of these forests, the specialisation of species to these habitats and biotic processes that favour difference over similarity. The spatial assembly of tree species at the community level is determined by abiotic and biotic environmental filters, and by chance (Fig. 1).

Abiotic characteristics of interest to plants include access to light, water and nutrients, and air and soil temperature. These characteristics are spatially structured in gradients or patches on a fine scale (a few metres), and overlap to form microhabitats. The set of abiotic conditions required for the survival of a species is called the fundamental ecological niche. Added to this are the biotic interactions that define the realised niche. In the literature, it is common to assign an ecological niche to a species, but the evolution of this niche over the ontogeny of trees has rarely been studied (ontogenetic niche).

A better understanding of the dynamic assembly of forests would make it possible to improve forest dynamics models and thus better predict the future of forests in the context of global change, and adapt management practices of these forests.

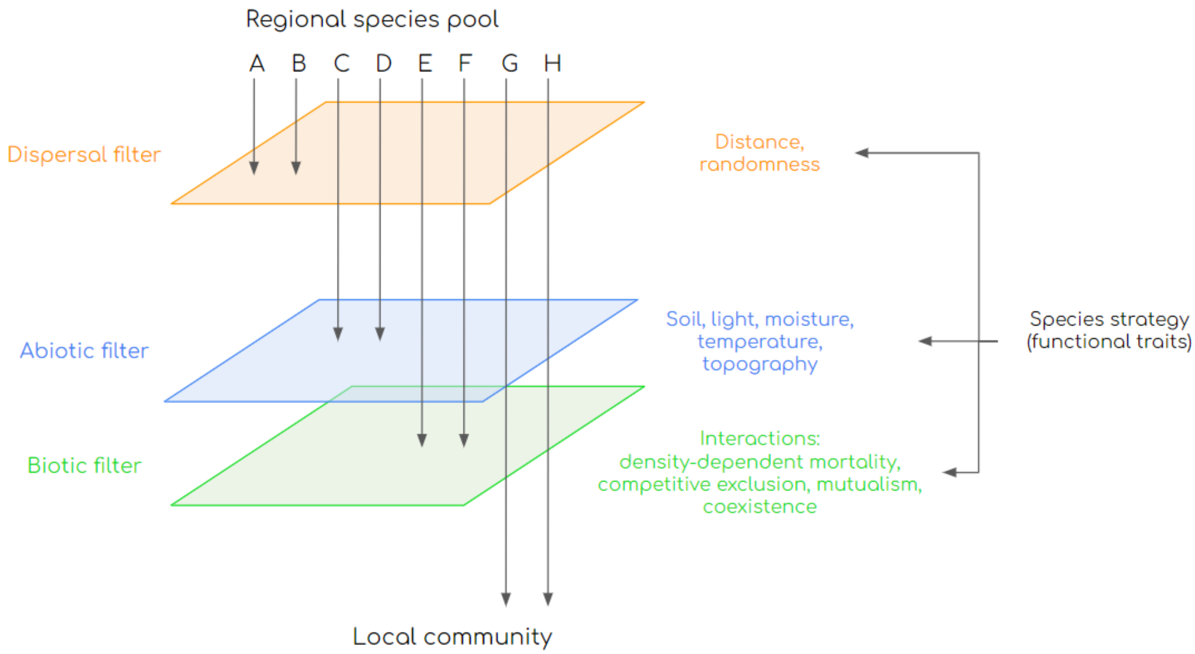

FIGURE 1 – Conceptual framework for community assembly based on a set of filters applied to the regional species pool.

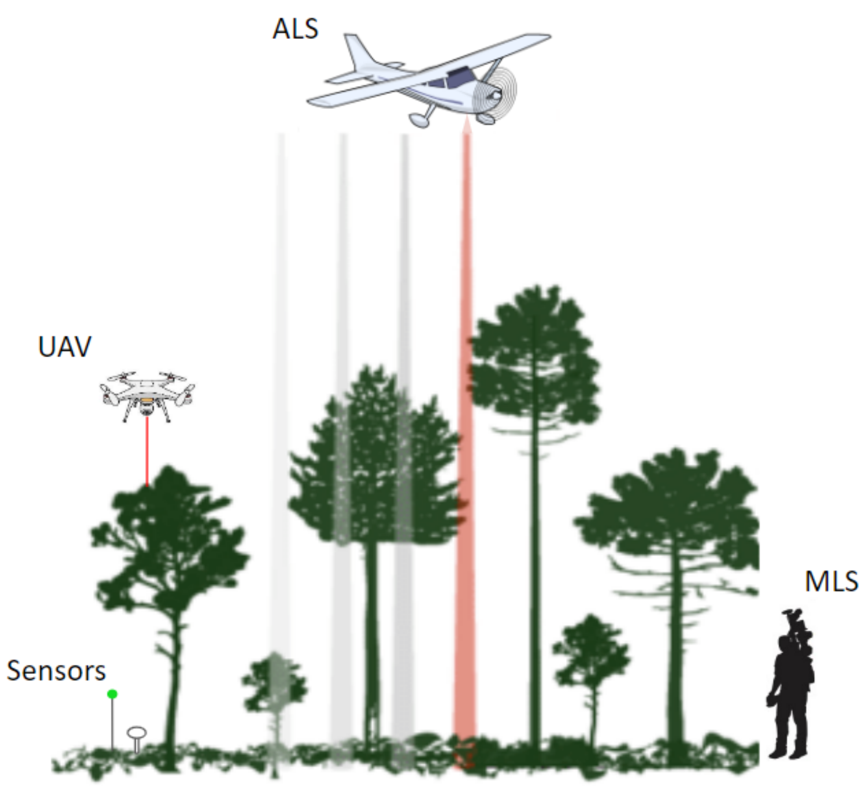

FIGURE 2 – Data acquisition methods.

Fires in socio-ecological systems : tropical and subtropical ecosystems

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| **Funding** | FISSA, ANR project |

Keywords : Soil carbon, forest soil, temperate forest, Bayesian statistics

The aim of my research is to understand how interacting social and ecological variables can affect fires at the landscape scale and which virtuous governance approaches can deal with these drivers, mitigating fire impacts. Within this frame, I focus on the specific process of deforestation in tropical and subtropical environments, looking at how it is altering natural fire regimes. I also seek to identify land governance strategies that can hamper these unfavorable alterations, with a consequent reduction of fire impacts.

My study areas cover regions of South America, mainly included in the biome of the Brazilian Cerrado. The methods I use to deal with these issues are mainly based on geospatial analyses and statistics, with recurrent use of machine learning algorithms. Results of my research are expected to clarify how complex processes, such as deforestation, are affecting fire regimes in different regions and which are the best governance practices to counteract these strong anthropogenic pressures. These findings will support the conception of guidelines for an integrated land management aimed at creating a fire-resistant and resilient landscape.

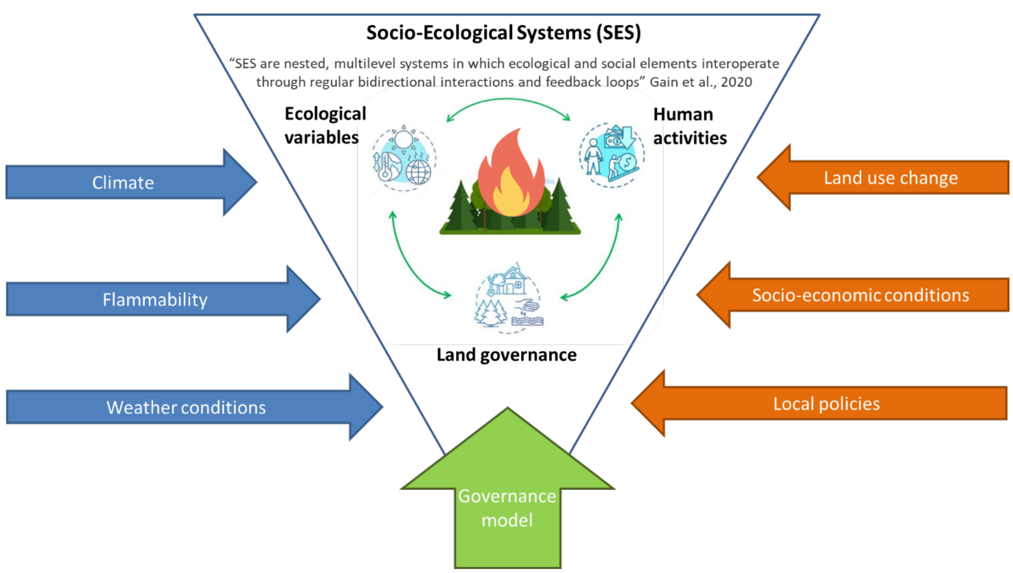

Figure 1 – Conceptual framework of my PhD research project.

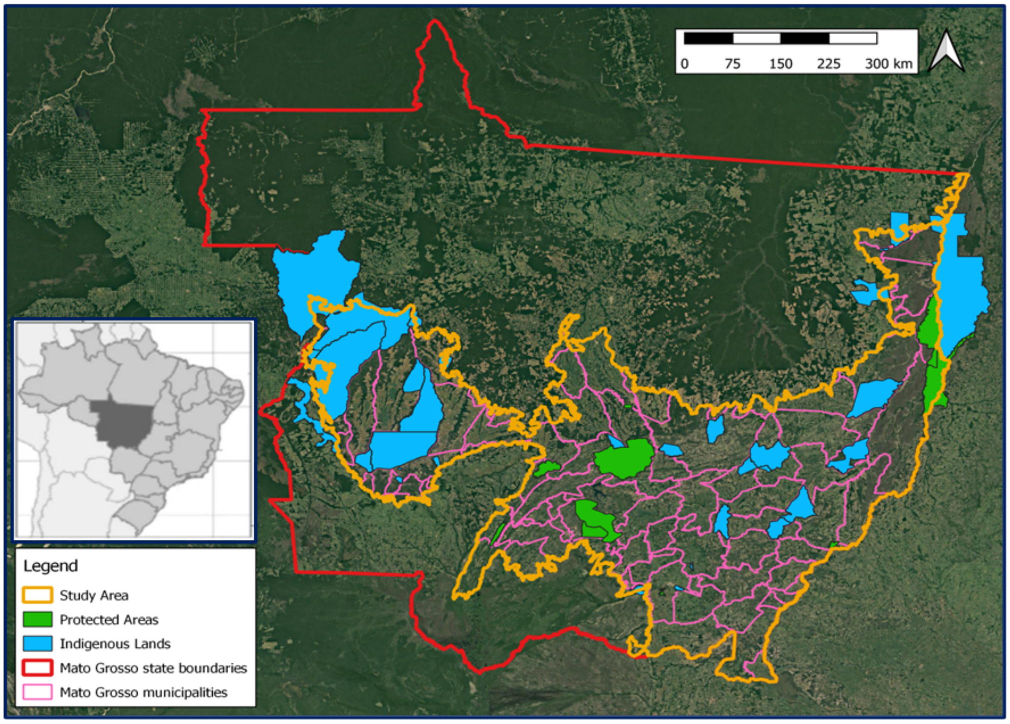

FIGURE 2 – Study area of my third chapter, focused on deforestation effects on the Brazilian Cerrado fire regime, and administrative boundaries.

FIGURE 3 – The Brazilian Cerrado biome.

Biotic interactions between alien plants and threatened trees endemic to the Mascarene islands

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Funding ANR

Keywords : Biotic interactions - Invasion mechanisms - Threatened endemic species - Island systems - Community-level species distribution models (jSDM)

The composition of plant communities on oceanic islands depends on their isolation, along with the natural dispersal capacity of organisms from landmasses ([1]). Introductions and extinctions have occurred on islands for millions of years, but human activities have increased the frequency of these events in unprecedented ways over the past few centuries ([2]).

Indeed, humans have introduced accidentally or purposely a large number of exotic species, a subset of which have become invasive ([3]) and have deleterious effects on native species ([4] ; [5]). Among those effects, IAS have contributed to 60% of recorded global extinctions and are the sole driver in 16% of recorded global extinctions ([6]). Yet, the biotic mechanisms allowing alien species to influence community structure still need to be investigated ([7]).

How alien mammal predators drive populations of preys to extinction is quite intuitive and well documented but, for plants, it appears much more difficult to identify the links between biological invasions and the decline of native populations. Invasive alien plants have been hypothesized to outperform some native species either by directly monopolizing resources or, indirectly, by facilitating other exotic species ([8]), breaking mutualist interactions among native species ([9]), or altering the environment ([10]).

Identifying invasion mechanisms is even more complicated for long-lived organisms such as trees because of an important time-lag between disturbances and the effective death of individuals (extinction debt ; [11]). Thus, it may be more relevant to consider the extinction as the result of a sequence of events or thresholds ([11]), such as the local loss of individuals (reflecting the loss of genetic diversity), the loss of one or more populations in the wild, etc. However, such precise information is often lacking. An alternative solution is to use the IUCN Red List categories to formalize an extinction trajectory, e.g. LC (no particular reduction of the population), NT (the range or population size of the species has been reduced or is predicted to decrease), or CR (several populations have gone extinct, only some individuals or small populations remain). Interestingly, IAS have been shown to be fourth or fifth cause of species decline (VU, EN and CR) but the first cause of recent extinctions (EW and EX ; [12]). This could suggest that the mechanisms used by IAS vary along the extinction trajectory, but this has however never been studied before.

In this context, my PhD project aims to better understand the community-level mechanisms that allow IAS to displace endemic plants. More specifically, I ask : (1) what are the dominant processes that allow IAS to replace the native flora ? (2) do these processes differ along the extinction trajectory of native species ?

To address these questions, I will (1) conduct an extensive fieldwork to collect a large amount of field data on the state of threatened tree populations, on co-occurring native and alien plants, and on a variety of functional traits, (2) analyze interactions between threatened endemic species and IAS using community-level statistical models (jSDM), and (3) test different interactions between threatened endemics and IAS under controlled conditions.

My PhD project takes place in La Réunion, an island in the south-western Indian Ocean, which forms with Mauritius and Rodrigues islands the Mascarene archipelago. The arrival of humans in these islands, although late, led to a significant decline in native vegetation, and the extinction of several animal and plant species ([13]). The archipelago is now among the territories with the most naturalised and invasive alien species in proportion to the native flora ([14]), making it a relevant study site of the extinction dynamics of endemic trees in exotic-dominated ecosystems.

The results will allow to monitor trends of threatened tree populations (decreasing, stable or increasing). As species extinction risk increases, I expect the strength of interactions between threatened endemics and IAS to increase, and the population size to decrease. I also expect the mechanisms disrupting the community to vary along the extinction trajectory, with a decreasing number of mechanisms increasing in relative influence as the species' extinction risk increases.

Hopefully, the results provided by this work will make it possible to better understand the mechanisms underpinning IAS success, which is urgently needed to prioritise and implement conservation strategies to locally reduce the loss of island endemic plants.

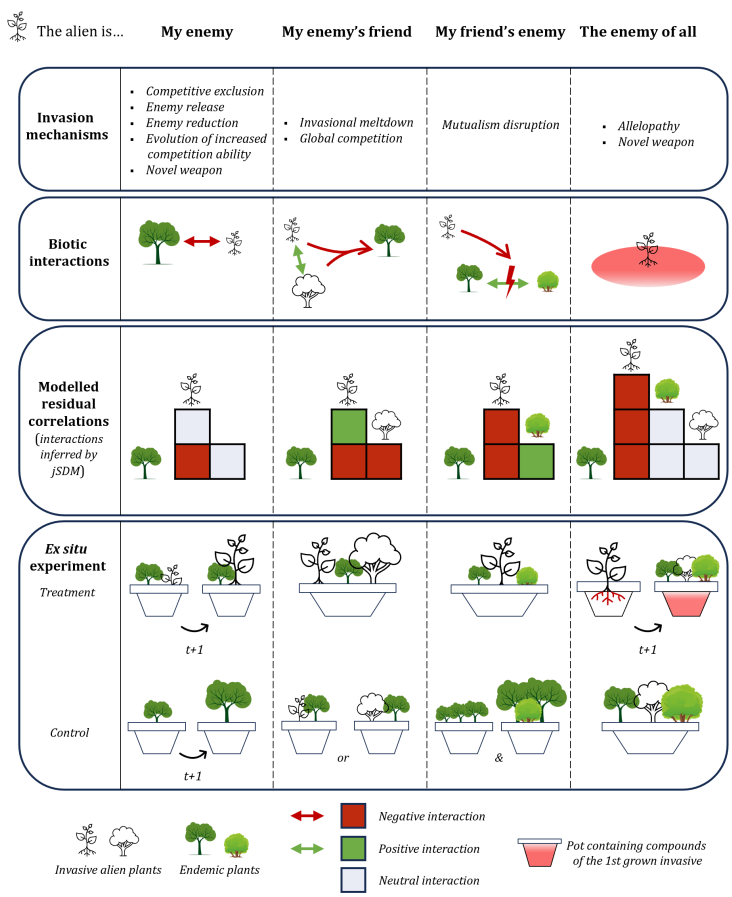

Figure 1 – Schematic representation of the expected patterns of different groups of invasion mechanisms described in the literature (according to the nature of the invasive-endemic interaction), according to the different approaches we chose to consider during my PhD project to investigate them (in rows, from top to bottom) : hypotheses, in natura observations during inventories, expected model outputs, and experiments in controlled conditions.

Trace the evolutionary history of plant forms and function

Author Artémis Anest (UMR AMAP)

Plant form diversity widely varies across environments, and phylogenetic groups. While it is acknowledged that plant structure is related to ecological performances [15], [16], the evolutionary trajectories explaining plant shape diversity remain poorly understood, especially considering the whole plant structure and with regard to the environment.

My research aims to understand the relationship between angiosperm plant form, environmental constraints, and evolution [17], [18]. These investigations have provided valuable insights into the adaptive strategies that plants employ to establish in diverse climates, and provided support for classifying traits of interest for 1) taxonomy, 2) ecology, 3) and evolutionary ecology (Fig. 2). Using this recently developed approach, my project aims to understand how the diversity of angiosperm plant form relates to environmental constraints and trough their evolutionary history.

In collaboration with Kew Royal Botanic Gardens and Berlin Botanical Garden, we will conduct investigations into selected plant families. These families include Euphorbiaceae, Combretaceae, Lauraceae, Thymelaeaceae, Urticaceae, Celastraceae, and Rhamnaceae (Fig. 3). We are using a multidisciplinary approach that integrates phylogenetic analyses, architectural descriptions, biogeographical studies, and ecological assessments. By investigating the structural diversity, ecology and biogeography of these plant groups, we aim to construct a comprehensive picture of the interplay between plant form, ecological filters and trait evolution throughout deep time history.

To achieve this, we will focus on three key objectives :

— Describe the architectural and functional diversity of various groups of Angiosperms clades.

— Analyse the biogeographical and ecological history of these plant groups to understand how the environment has influenced the colonisation and establishment of clades in various biomes and continents.

— Explore the ways in which environmental factors have shaped the evolution of plant structures and assess the significance of these adaptations in the context of plant taxonomy, ecology and evolution.

The completion of this project will have both immediate and long-term implications for the fields of evolutionary ecology and conservation.

It will advance our understanding of the intricate relationships between plant architecture diversity, present and past environmental constraints, and the evolutionary history of angiosperms, thus providing foundations for future research in these areas.

From a conservation perspective, this project's findings can help inform and shape conservation efforts. By recognizing the significance of specific adaptations and their responses to environmental changes, we can develop more targeted conservation strategies.

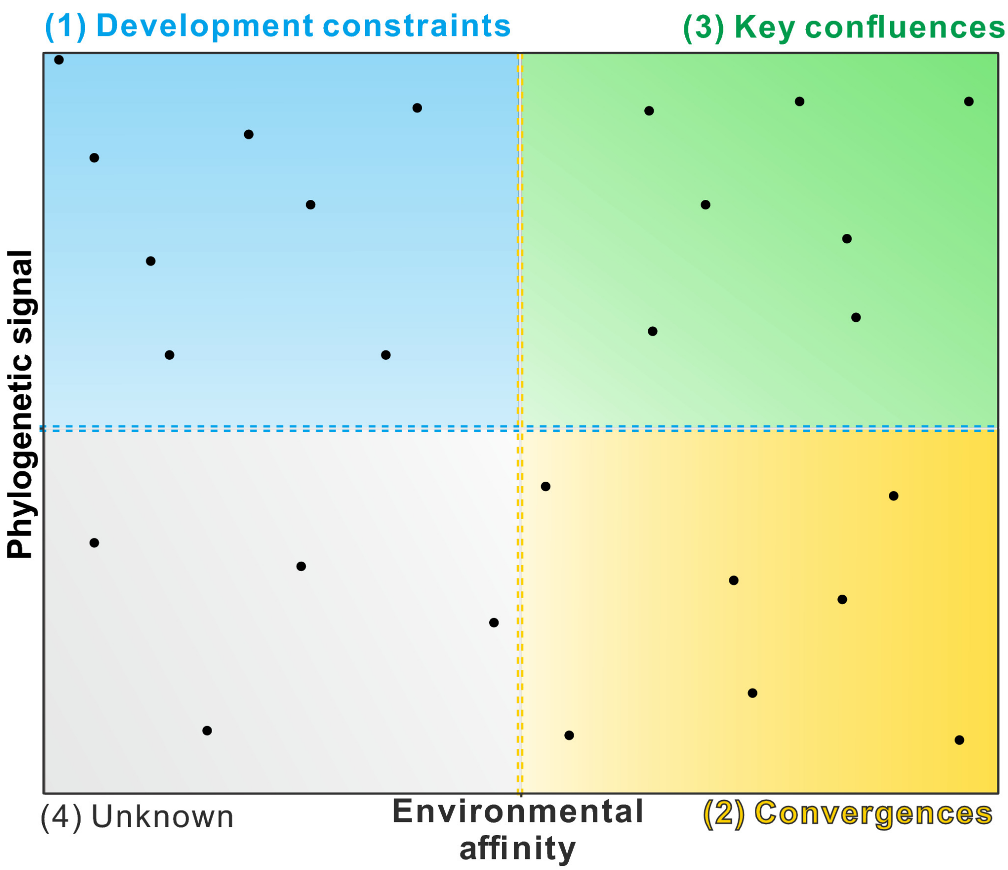

FIGURE 2 – From [17]. Conceptual framework for extracting the information associated with each trait for a plant clade. The measurements for each trait of both phylogenetic signal and environmental relationship can be divided into four different affiliation quadrants : (1) the top left quadrant (in blue) indicates traits with strong phylogenetic signal only, representative of strong developmental constraints ; (2) the bottom right quadrant (in yellow) indicates traits with significant environmental dependency only, representative of convergences under the tested environmental driver ; (3) the top right quadrant (in green) indicates traits with strong phylogenetic signal and significant environmental dependency, potentially representing 'key evolutionary confluences' sensu Donoghue & Sanderson (2015), that is, trait innovations followed or preceded by evolutionary shifts in climate regime which together could have triggered evolutionary radiations ; and (4) the bottom left quadrant (in grey) indicates traits with no phylogenetic signal and no dependence on the tested environmental driver, which may be convergent under other environmental drivers not tested here or be nonadaptive.

FIGURE 3 – Example of structural diversity in a plant clade : the case of Euphorbia genus.

Lauraceae's structural diversity and evolution

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Funding	University of Montpellier

Keywords : Plant architecture, Lauraceae, evolution, adaptation, ecology

Aim and Background

The family of Lauraceae is a large pantropical and globally distributed clade of about 2850 species within the basal Angiosperms. It is thought to have inhabited most low and middle latitudes of the northern hemisphere since the late Cretaceous [19]. *Laurus nobilis*, the eponym of the sub-tropical Laurel forests that historically extended over much of the continent of Gondwana and Laurasia during periods of much warmer and humid climate, is the only species that persists in southern Eurasia today. Since most of Lauraceae genera remains confined to more stable mesic environments, the question therefore arises : are there specific evolutionary adaptations that allow *Laurus nobilis* to proliferate in the seasonally dry and temperate environment of the Mediterranean basin and figure as a stable component of the flora of southern France and the adjacent coastal areas ?

Contrary to the stable and humid climate of Laurel forests, Mediterranean-type climate is characterized by an annual period of drought coupled with high temperature, alternating with temperate cold and wet winter. Plants living in this environment need to be adapted to prolonged periods of low to no water availability, heat, and sun radiation, as well as to periods of high rainfall and low winter temperatures, that negatively impact the photosynthetic activity [20], [21]. The adaptations acquired by species capable of living in these two highly contrasted environments thus ought to be distinct from those of most Lauraceae.

The species ability to establish itself in certain environments is facilitated by the species morphological traits [22]. In the Mediterranean, the summer dry period is responsible for the diversification of slow growing, sclerophyllous vegetation, that now dominates the local biome [22] ; [23]. The defining traits of sclerophyll plants are great longevity and an evergreen habit, bearing structurally reinforced leaves with xeromorphic traits. Further morphological and physical adaptations can involve leaf insertion angle and phyllotaxis [24], morpho-physiological adaptations ([25] ; [26]), modifications in root architecture [23] *(references therein)*, and phenological shift [27] ; [28]. Some Mediterranean plants are subject to seasonal dimorphism, displaying a substantial difference in the lengths of their winter and summer shoots ([29]). Another growth strategy exploited by plants in the semi-arid environments is adopting a shrubby habit ([30]). These diverse adaptations illustrate that plants structural traits have been selected by the environment through different trajectories.

Various spatial and temporal adaptations allowing species to overcome environmental constraints display as features of plant anatomy and growth, the study of which is approachable through the non-invasive methods of plant architecture. This method, developed by [31], allows us to characterize the whole plant structure across space and trough time. Through this lens, various strategies of space occupation can be illustrated with examples of evolution of drought-adaptive traits, such as the modification of axes into spines, or a transfer of photosynthetic function from leaves into the stem ([32]), both of which allow for the reduction of the overall amount of foliage. In both instances, such trait acquisition serves to decrease the transpiration surface and thus mitigates water loss. Another example is the plants phyllotaxis, determining the distribution of axillary meristems and possibilities of ramification. This can be secondarily modified to serve as a competitive strategy for access to light, as well as to regulate the amount of light intersection and thus prevent overheating and excess radiation. Adaptations also concern sequential events in time, involving the growth and branching processes. These can, for instance, result in seasonal dimorphism, which is a response adopted in periodically diverging environmental conditions, securing the persistence of growth and of photosynthetic capacity, while minimizing transpiring surface and regulating energy investment. This can be observable as differences in the length and morphology of alternating growth units ([29]), in the morphology of foliage ([33] ; [29]) or in building of reproductive structures ([34]). Finally, the adopted growth habit reflects the trade-off between plants physiological needs and the given local environmental constraints ([30] ; [25]).

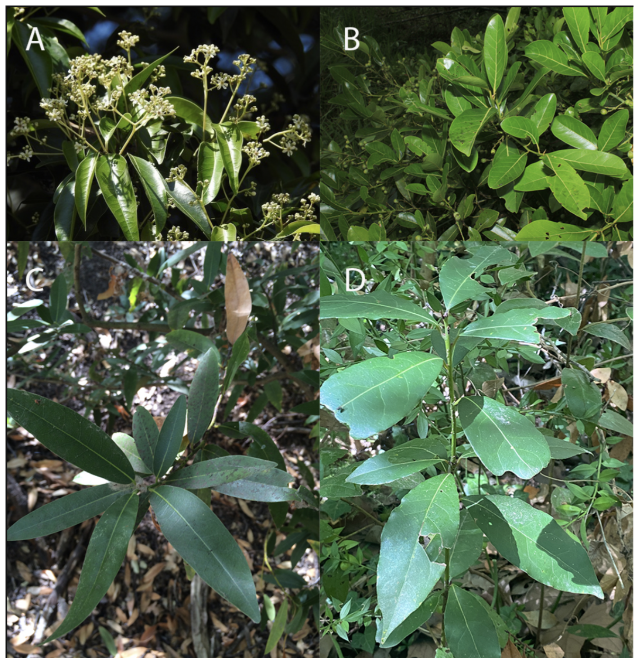

Figure 1 – Some representatives of Lauraceae : (A) *Nectandra coriacea* (B) *Ocotea floribunda* (C) *Umbellularia californica* (D) *Laurus nobilis*

One of the important limiting factors in the Mediterranean habitat is the seasonal availability of water, which is an abundant resource in the laurel forests. The family Lauraceae shows relatively high niche conservatism as most of its species are distributed in tropical regions since the establishment of the Mediterranean climate in the Pliocene ([35] ; [36]). The survival of few Lauraceae species in Lauraceae-untypical ranges suggests that specific adaptations have allowed this species to establish in these habitats or to be maintained geographically while the regional climate underwent important changes. Investigating the degree of similarity of the recently diverging (Pliocene epoch) species of Lauraceae with the typical Mediterranean-type flora can help us identify the exclusively acquired traits which have allowed *Laurus nobilis* to survive in the Mediterranean climate.

Since several recent studies showed that the expression of diverse plant forms is a response to various environmental conditions ([24] ; [37] ; [38] ; [39]), here, we wondered, how the structural and developmental traits of *Laurus nobilis* characterizing the species strategy have influenced its establishment or maintain in different habitat range compared to its relatives ? To answer this question, this study aims to (1) describe the architecture of *Laurus nobilis* throughout ontogeny, (2) identify the key traits in *Laurus nobilis* architecture that allow this species to survive in its current habitat and (3) investigate the convergences and divergences of characteristics with other members of the family and determine the traits that set *Laurus nobilis* apart from other Lauraceae.

Our hypotheses are that (1) there are specific architectural traits limiting Lauraceae to certain climates, (2) Lauraceae living in different habitats display different architectures and (3) different architectural traits have been selected under different environments.

To test these hypotheses, we will use (1) the architectural analyses (sensu [40]) and (2) compare the traits described to other Mediterranean species through fieldwork/literature ; finally, we will (3) search for the major differences compared to tropical Lauraceae by picture analysis and through fieldwork.

This will allow us to identify the (1) the diversity of architecture in Lauraceae, and (2) the major traits that are convergent within Mediterraneaan species, in contrast to (3) the traits of the tropical Lauraceae. In this last part, we also expect to identify what are the “signature” architectural traits for Lauraceae family that are stable at the family level, independently of their distribution.

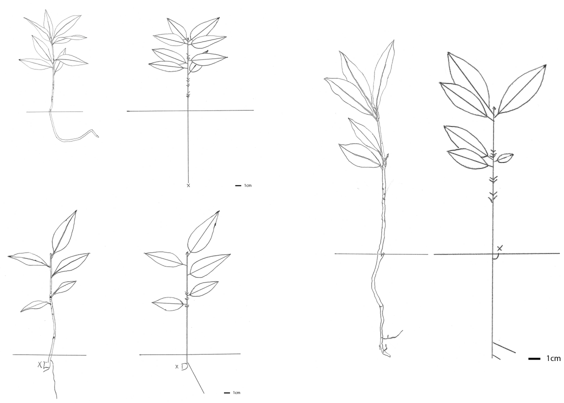

Figure 2 – Drawings and schemes of juveniles of *Laurus nobilis*. Scale indicated next to each pair.

Methods

We chose to start this study by analysing the architecture of *Laurus nobilis*, one of the single representatives of Lauraceae distributed out of the tropics.

The studied individuals have been sampled from the population of the Réserve du Lez Montpellier and Restinclieres. Precise measurements were taken, and drawings were made up to scale to compare different ontogenetic stages between each other.

The observed characteristics were : the presence of cataphylls, internode length, phyllotaxis and leaf size, position of axillar meristems and bud development, ramification, presence and position of reproductive structures.

Trait description and architecture analysis of *Laurus nobilis* sensu [31] and [40] using 10 architectural descriptors at the whole plant and the axis level :

— (I) Descriptors relating to the growth process at whole plant and axis level include (1) rhythmic vs. continuous growth ; (2) in case of rhythmic growth : assessment of the morphological differences in growth units, annual shoot.

— (II) Descriptors of the branching process include (3) immediate vs. delayed branching ; (4) monopodial vs. sympodial branching ; (5) rhythmic vs. continuous or diffuse branching ; (6) acrotonic vs. mesotonic or basitonic branching ; (7) hypotony, epitony and amphitony.

— (III) Descriptors of the morphological differentiation of axes include (8) orthotropy, plagiotropy and mixed axes ; (9) short vs. long axes ; (10) the position of sexuality and reproductive organs - terminal vs. lateral.

For the establishment of the architectural model the branched system and branching order was defined.

Preliminary results

The individuals analyzed so far were in early ontogenetic stages. The orthotropic axis of unbranched juveniles displays spiral phyllotaxis with rhythmic growth marked by the presence of cataphyll scars and periodicity of leaf building. A difference in leaf size of alternating growth units can be observed. For simply ramified individuals, the branching pattern is rhythmic, showing the presence of cataphyll scars at the base of newly built branches, suggesting a period of dormancy following branch development, pointing to a delayed development of branches. The number of growth units on the branches is equal to the number of growth units of the parent shoot above the point of branching. Differences in leaf size on branches are present, with leaves of up to two times the size at the distal end of the branch. The branches are monopodial with spiral phyllotaxis, giving rise to some orthotropic axes with more than 45° diagonal and some orthotropic axes with a wider insertion angle.

Pollination systems, floral scent specificity and overall floral trait diversity in natural orchid communities in Cameroon.

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Funding	ARTS IRD, CARN Aspire Grant Programme

Keywords : Floral scent chemistry, orchid pollination, volatile organic compounds, angraecoids, phylogeny, shadehouses, conservation, Central African rainforests.

Orchid (c.a 28,500 accepted species) [41] survival depends on their pollination, reproductive success, and biotic interactions [42]. They have various pollination mechanisms, often involving the production of volatile organic compounds (VOCs) that attract specific types of pollinators. However, the role of floral scents in pollinator attraction remains poorly understood for many orchid pollination systems [43], although the quantitative and qualitative proportions of species scents provide distinctive chemical signatures crucial to the specialization and evolution of pollination systems. Angraecoid orchids, a monophyletic group of approximately 780 species, are major components of Africa's wet and dry forests. Recent phylogenetic analysis of this clade clarified its taxonomy [44] and revealed the importance of mapping different floral traits, such as spur length, to explain the evolutionary success of certain lineages, particularly sphingophilous ones [45].

My thesis assesses floral scent variations, pollination mechanisms, and the phylogenetic variations of these pollination traits, focusing on angraecoid orchid communities found in Cameroonian rainforests. My first two objectives consist of comparing floral scent variations annually in (i) a range-restricted species, *Cyrtorchis letouzeyi*, between in situ and ex situ (shadehouse) environments (Figure 1), and in (ii) a widespread species, *Eichlerangraecum eichleirianum*, between three geographically distinct ($>$ 50 km) natural sites. My third objective consists of characterizing pollinator groups and pollination mechanisms (Figure 2) involved in the reproduction of two non-sphingophile species. My final objective aims to describe the floral scent profiles of about 40 angraecoid orchids from Cameroon and map them on an existing phylogenetic tree to determine whether the evolution of perfumes is consistent with the evolution of traits such as chromosome number, floral morphology and leaf DNA.

All floral scents were collected using the dynamic headspace method [46], and pollinator identification was performed using the PICT method [47]. To date, our results have revealed three novel pollination systems described for two short-spurred angraecoid orchids : (i) Melittophily in *Bolusiella zenkeri* with tiny, white flowers and Dipteran pollination, and phalaenophily in *Diaphananthe bidens* with orange flowers. Floral scent profiles are currently described for 32 species (249 of 388 samples analyzed). This resulted in the identification of 289 different VOCs mainly constituted of sesquiterpenes, monoterpenes, and several "unknown" compounds.

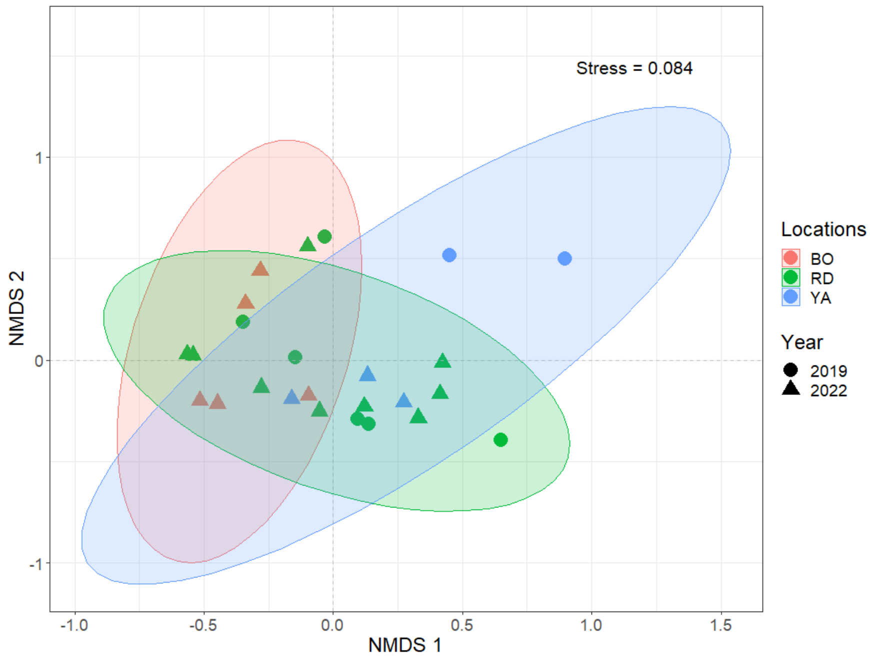

FIGURE 1 – Non-metric multidimensional scaling (NMDS) based on the Bray-Curtis dissimilarity index of relative proportions of VOCs emitted by C. letouzeyi in Yaoundé (YA), Bouamir (BO) and the natural site (RD) in 2019 and 2022 (stress =0.084)

FIGURE 2 – Field observation photographs of pollinators of two morphologically distinct angraecoids surveyed in situ. Pollination of : (A) Bolusiella zenkerii by stingless melipone bee cf. Dactylurina staudingeri and (B) Diaphananthe bidens by crane-fly (Tipulidae) and (C) Diaphananthe bidens by settling moth cf. Thermoniphas leucocyanea. (photo credit : Messado L.)

Mathematical modeling and analysis of spatio-temporal models dedicated to tree-grass dynamics in humid savannas.

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Funding	Étudiant-salarié

Keywords : Savanna – Fire – Partial Differential Equation – Qualitative Analysis – Travelling Wave – Nonlocal Competition – Nonlocal Facilitation.

Vegetation biome encompasses in wet ecosystems, self organized physiognomies that traduce complex dynamical processes leading to homogeneous distributions of forests, grasslands and savannas, to heterogeneous distributions of trees and grasses. Spatio-temporal patterns of vegetation, are characteristic feature of wetland ecosystems occurring in all continents. The development of a better understanding of their spatial dynamics, is an issue of considerable ecological and social economical importance, by regulating global climate and provides materials need for human.

Mathematical modelling is a useful tool to describe dynamics of complex systems and, several mathematical models have been devoted to the study of tree-grass dynamics in savanna ecosystems, but with a scarcely attention, of spatial mechanism of tree and grass interactions that translated in space. This work dedicated to the modelling and the analyse via partial differential equations on tree and grass dynamics in humid savannas is divided in two main parts. In the first part, we propose and analyse a spatio-temporal model of tree-grass interactions in humid savanna. This first model, is based on two nonlocal reaction-diffusion equations with kernels of intra and inter specific competition and also a kernel indirectly acting as facilitation in term of reduction of fire effect on tree mortality ; all off these in the reaction part of the model.

The diffusion part is modelled via the Laplace operators considered in a one spatial domain. A qualitative analyse of this model reveals several ecological thresholds that shape the overall dynamics of the model. Thanks to linear stability analysis, the model account for the occurrence of space inhomogeneous solutions. All of these lead us to conclude that, the interplay between nonlocal competition and nonlocal facilitation, can explain the spatial periodic structuring sometimes observed in humid savannas. In the second part of this work, we consider nonlocal seed dispersal, as to describe the propagation in space of both tree and grass biomass. We therefore replaced, the Laplace operators by integral operators, and, we focus on the existence of travelling wave connecting the grassland homogeneous steady state to the forest homogeneous steady state of the model.

A qualitative analyse of this reaction dispersion model, leads to the characterization by a mathematical expression depending on several parameters of the model, of the minimal wave speed that controls the forest encroachment into the grassland. We therefore found that, the length of tree seed dispersal and the fire frequency can control the wave propagation.

FIGURE 1 – Airborne image of a savanna.

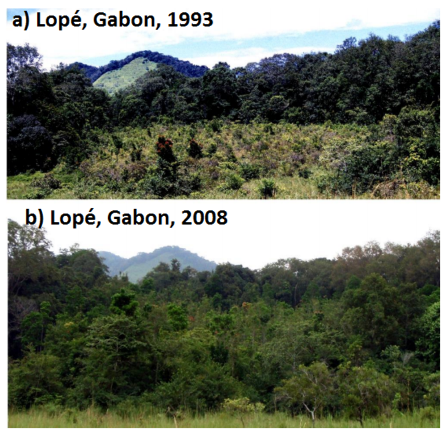

FIGURE 2 – Example of a forest expansion over Lopé, Gabon in 1993 (a) and 2008 (b)

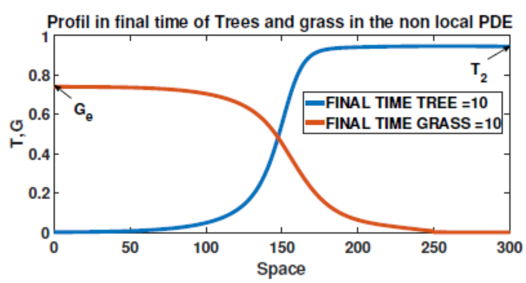

FIGURE 3 – Travelling wave example

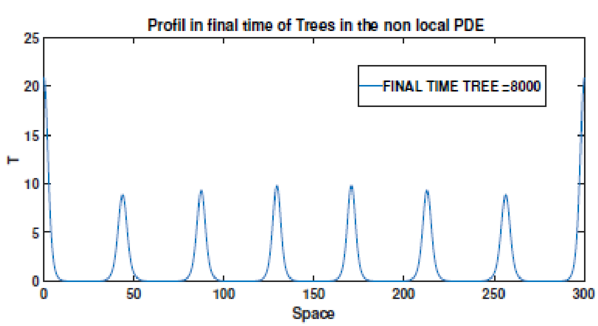

FIGURE 4 – Tree distribution pattern

Exploring sources of instability in the spectral reflectance of a tropical canopy in French Guiana.

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Funding	CNRS - Institute of Mathematics for Planet Earth

Keywords : Remote sensing, Hyperspectral, Lidar, Machine Learning

This thesis aims at developing a method for high throughput inventories using airborne remote sensing coupling lidar and hyperspectral imagery.

The interest of this thesis would be to develop a methodological reflection and mathematical / statistical processing of the hyperspectral signal to improve the genericity of the spectral characterization of forest canopies from hyperspectral imagery (atmospheric correction and BRDF effects), which would be organized in three parts :

- A first investigation of the variation of a tropical canopy reflectance given different identified and notable sources of variability.
- A study on the influence of various data encoding methods capable of producing a representation of an hyperspectral reflectance, resilient to previously explored sources of variability using various subspace encoding techniques.
- The production of a method for classifying tropical species, taking into account the stabilized representation of the spectrum and the potential limitations of such a classification operation in the context of a tropical forest, mixed canopy, presence of lianas, different phenological states in the crown.

My current work is still focused on the first objective of my PhD, I use repeated overflights of two tropical forest sites in French Guiana to investigate factors affecting spectral similarity across dates, see fig. 2. By carefully pairing repeated acquisitions of the same area, various sources contributing to spectral distortion within and across dates are explored.

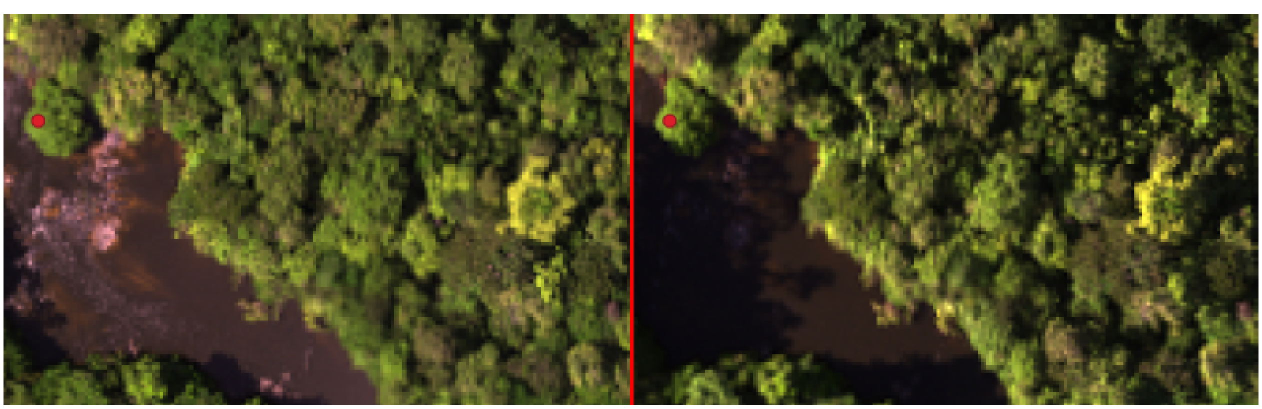

Figure 1 – Different acquisitions of the same area in RGB false color from an hyperspectral acquisition.

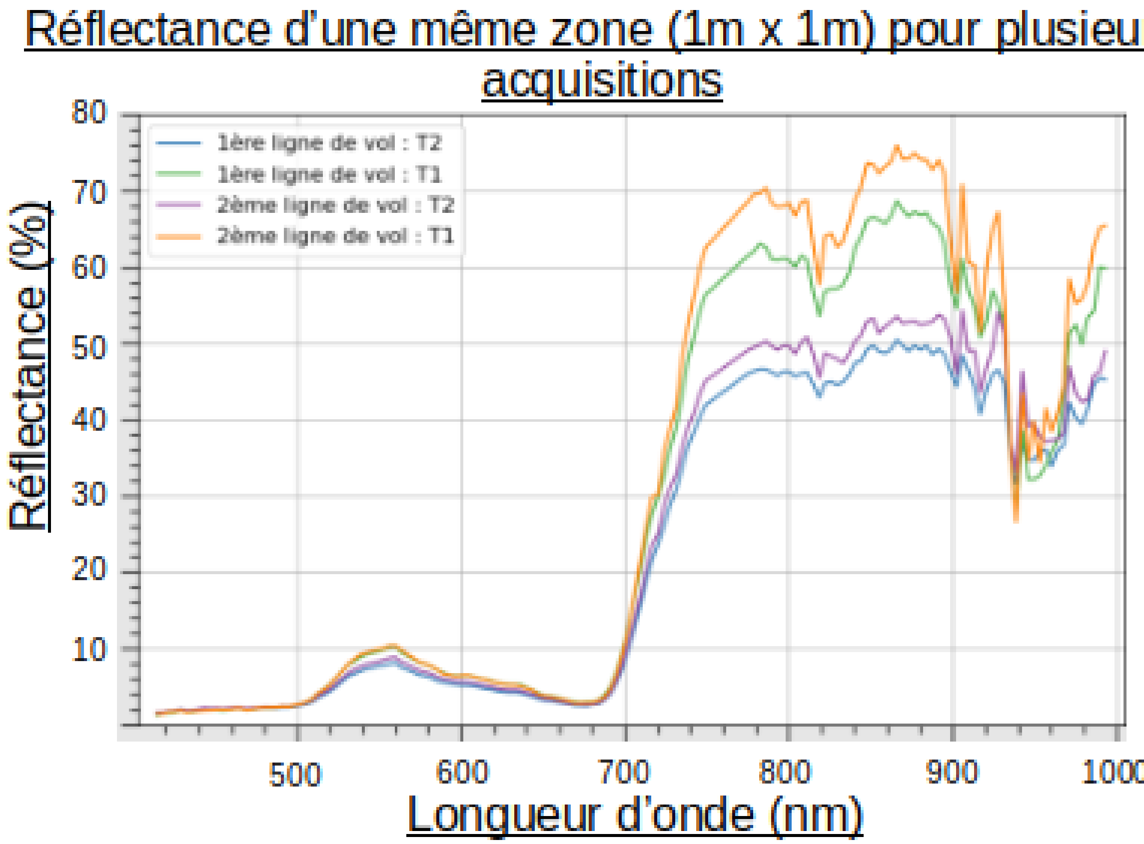

FIGURE 2 – Several spectra of the same area (red dot in fig. 1) given different hyperspectral acquisitions.

FIGURE 3 – Cool image of a plane over some weird forest (probably an AI output), stolen from `https://www.123rf.com/photo_43082054_passenger-plane-over-a-forest.html`

Leaf/wood discrimination in ULS lidar using neural networks

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Funding	Université Grenoble Alpes

Keywords : UAV, Deep Learning, Semantic Segmentation, Lidar, Class Imbalance, Point Cloud Wave – Nonlocal Competition – Nonlocal Facilitation.

Separating leaf from wood returns in forest lidar point cloud is a commonly required pre-processing step to estimate leaf area or wood volume. This key step is particularly challenging in tall dense hyper-diverse evergreen forests.

Unmanned aerial vehicle laser scanning (ULS) has emerged as a premium solution to collect high density point clouds ($10^3/m^2$) rapidly over several hectares of forest. However, the level of detail remains much lower than what is typically achieved using multiple TLS positions ($10^5/m^2$). In particular in the lower canopy.

In this study, we compared three semantic segmentation procedures applied to TLS and DLS point cloud over one-ha of moist tropical forest in French Guiana. Both point clouds were acquired in October 2021. A subset of 418 trees were manually isolated in the TLS point cloud and a semi-automatic segmentation of leaf and wood returns was conducted on each isolated tree. Labels were then transferred to the co-registered ULS point cloud based on nearest neighbours. These two datasets (TLS and ULS) were used as a reference to evaluate the three algorithms.

The three procedures to evaluate were 1) A geometric leaf-wood classification method (Lewos) 2) a deep learning (DL) approach (Forest Structural Complexity Tool : FSCT) and 3) A DL algorithm we developed. The latter was based on PointNet++ that combines convolution networks on 3D point clouds, quantitative information attached to each point and prior spatial and geometrical and topological information related to the neighbourhood of each point.

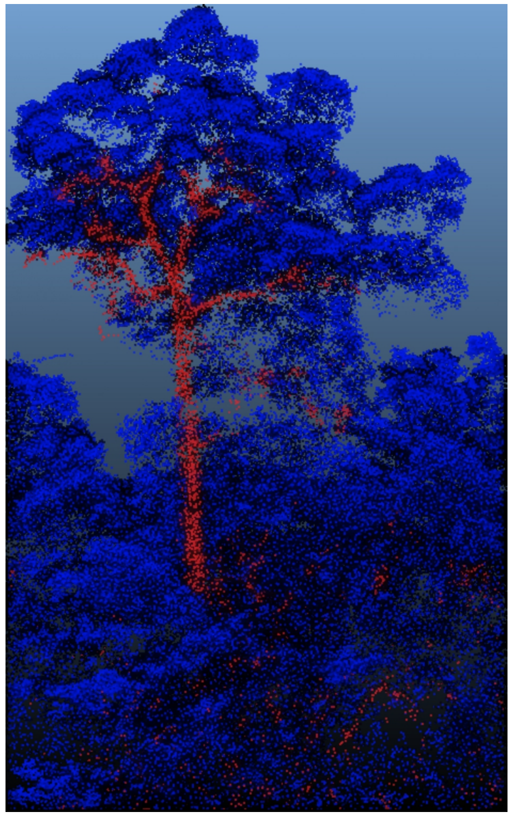

FIGURE 1 – Ground Truth of ULS data

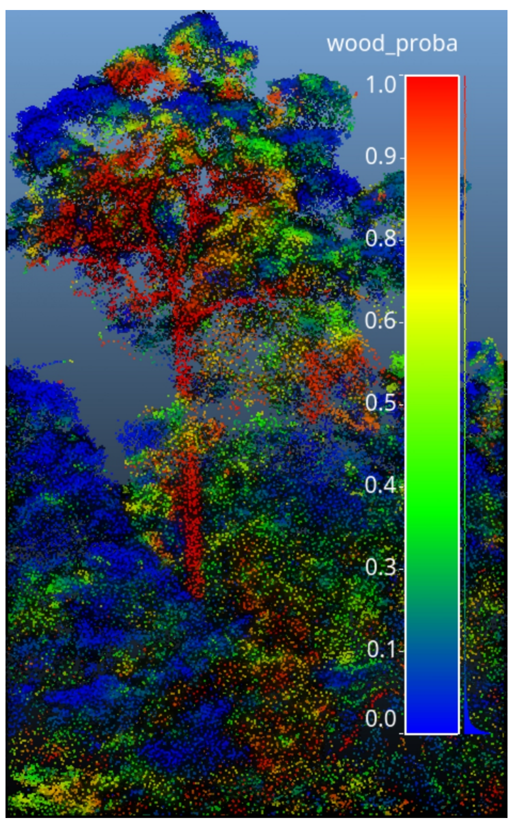

FIGURE 2 – Qualitative results of SOUL model on ULS test data, where blue represents leaves and red represents wood incorporating gradient colors for transitional probability

Predicting future biodiversity trajectories using artificial intelligence

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Funding INRIA, GUARDEN

Keywords : Artificial intelligence, Biodiversity monitoring, Deep learning, European flora, Habitat type, Phytosociology, Vascular plant species, Vegetation plots classification

During the first year of the PhD, we focused on the accurate classification of habitats, which is essential for effective biodiversity conservation and management. The goal of our work was to harness the huge potential of cutting-edge technology to advance habitat monitoring in the European Union (EU) by integrating deep learning techniques. We aimed to develop and evaluate new algorithms and models capable of assigning vegetation-plot records to the habitats of the European Nature Information System (EUNIS), a widely used reference framework for European habitat types, ensuring the generalization and robustness of our framework.

The framework was designed for use in Europe and adjacent areas such as Armenia, Azerbaijan, Kazakhstan, Morocco or Turkey. It may work well in Northern Africa and Western Asia, but the misclassification risk is higher there because it was not thoroughly tested for these regions as the data was very sparse. We leveraged modern and innovative deep learning techniques, such as transformers (i.e., models with attention components able to learn contextual relations between categorical and numerical features) or feedforward neural networks (i.e., fully connected neurons with a nonlinear kind of activation function) that we trained using k-fold cross-validation (CV) on vegetation plots sourced from the European Vegetation Archive (EVA), to show that they have great potential for recognizing habitats based on tabular data.

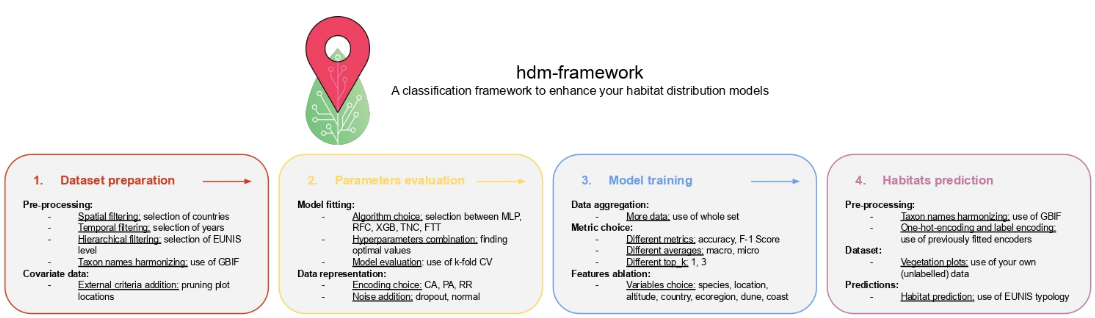

FIGURE 1 – hdm-framework, a classification framework to enhance your habitat distribution models

We experimented with different network architectures, feature encodings, hyperparameter tuning and noise addition strategies to identify the optimal model for habitat classification. We also used an independent test set from the National Plant Monitoring Scheme (NPMS) to evaluate the performance of our selected algorithm on external data, in order to compare their results against the traditional expert systems commonly employed in this field. We explored the use of deep learning applied to floristic and plot-location criteria, and we developed a powerful and comprehensive framework for habitat classification containing a wide range of models.

Our selected algorithm, applied to a large majority of the European terrestrial and marine habitat types, significantly improved habitat classification accuracy, achieving a remarkable improvement of over twofold compared to the previous state-of-the-art (SOTA) method on an unseen dataset (remarkably, after standardizing the scientific names of plant species, our model even reached an accuracy of 88.74% on the EVA data, outperforming the expert system by more than 3.5 points even though the ground-truth labels were established by the expert system itself).

The framework is shared and maintained through a public GitHub repository, supported by extensive documentation and accompanied by helpers and tutorials to facilitate its widespread adoption by external users within the community.

Our results demonstrate the potential benefits of the adoption of deep learning techniques for improving the scalability, efficiency and accuracy of vegetation classification processes while highlighting the importance of incorporating advanced technologies into habitat monitoring and conservation efforts, as deep learning algorithms have shown to be best suited for habitat type prediction than expert systems.

The framework we developed can be used by researchers and practitioners to accurately and efficiently classify habitats, thereby facilitating effective management and conservation of biodiversity in Europe and beyond, as well as for educational purposes, promoting broader accessibility and collaboration in the field and fostering continued advancements in biodiversity monitoring and preservation.

Climatic, oceanic and sedimentary conditions of natural renewal of mangroves in French Guiana for an adaptive coastal protection strategy

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Funding	PPR Océan & Climat

Keywords : Mangrove, coastal biodiversity, erosion, hydro-sedimentary dynamics, mud bank, ecological restoration, nature-based solution, French Guiana,

Are there key indicators of the natural functioning of mangroves that would allow us to better understand and anticipate how ocean and climate processes impact the coastal interface ? The question arises with regard to the persistence of mangroves for more than 60 million years, during which climatic and tectonic upheavals have followed one another. To address this issue, the mangroves of French Guiana have a unique story to tell as the renewal of coastal mangroves is rapid and seems to compensate, according to the phases of silting, the losses by erosion. However, as everywhere in the world, the oceanic and climatic processes are changing, in particular the swell regimes that arrive at the coast : the maintenance of the ecosystem could be thwarted by an accentuated remobilization of the muddy substrate on which the young mangrove develops.

Thanks to a better understanding of the natural settlement patterns of local mangroves, we will try to reveal the vulnerabilities that affect mangrove coasts. In practice, the aim is to characterize the spatial expansion and growth patterns of mangrove seedlings according to hydro-sedimentary and ecological factors considered as determinants of mangrove establishment, using field surveys and repeated fine-scale spatial observations on several sites in French Guiana.

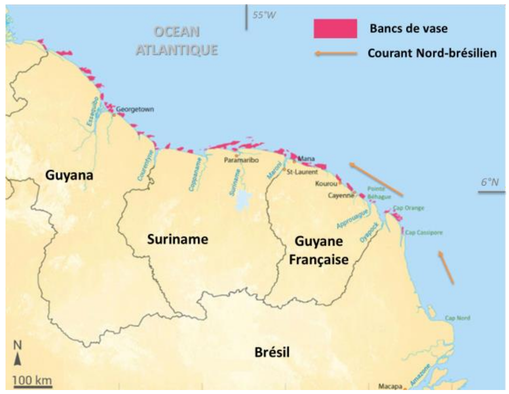

FIGURE 1 – The Guiana Shield is subject to the Amazonian sediment dispersion system. Under the combined effect of swells and coastal currents (including the North Brazilian Current), mud banks of several tens of square kilometers are formed from Cape Orange. Mangroves can develop on these consolidated muddy platforms. Between each mud bank, erosion is severe, and the mangrove can disappear. The whole system moves from the south of French Guiana to the Orinoco delta at the border of Guyana and Venezuela.

FIGURE 2 – Different 'faces' of Guianese mangroves. Colonization phases can be particularly rapid and involve several tens of hectares in a few months [48]

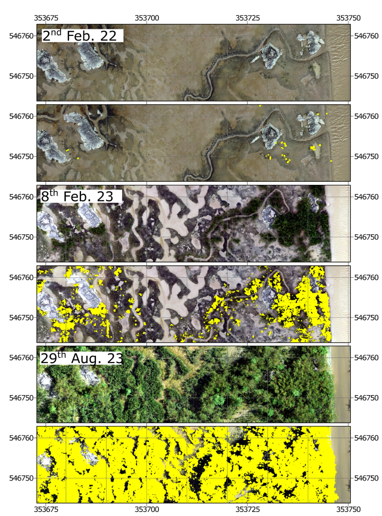

FIGURE 3 – Mangrove expansion during 19 months recorded by photogrammetrics drones on a small area of the study area of the mud bank of Cayenne. Three pair of date (Feb. 22, Feb. 23, Aug. 23) with the raw orthorectification and the vegetation index applied on it. Grid is in meters.

Is global warming blowing hot or cold on high mountain plants ? Reduced snow cover, nursery plants and adaptations to cold in temperate and tropical latitudes.

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Funding GAIA funding competition

Keywords : community ecology, global change, plant-plant interactions, elevation gradients, chronosequences, functional traits, nurse plants

The acceleration in global warming over the last few decades is changing the biotic and abiotic factors that define ecological niches. It is forcing biodiversity to adapt to these new conditions or to migrate in reduced time steps ([49]). In high mountains, above the upper limit of the forest, the so-called 'alpine' plant species are sentinel species : they are subject to more intense warming than at lower altitudes, and their responses are indicative of the overall responses of biodiversity over a longer period. At temperate latitudes, alpine species are protected from low winter temperatures by seasonal snow cover ([50]). On the other hand, they have a particularly short vegetative growth period and develop dwarf, low-growing aerial life forms. In contrast, tropical alpine species thrive in habitats where the duration of snow cover is negligible. Therefore, these species are adapted to low night-time temperatures and have a vegetative growth period that can extend over the whole year ([51]). In the northern Andes ([52], Grime C, S and R strategies coexist, whereas most temperate alpine species are classified in the S strategy ([53]). Global warming is leading to a reduction in the duration of snow cover in temperate zones and significant changes in the distribution of temperate species ([54]). The absence of snow in the tropics suggests that the effect of warming on alpine species is different, but there is currently no comparative work to show this. Furthermore, in alpine communities, nursery plants have significant positive effects on other plants ([55]). It is expected that these nursery effects will promote the extension of the distribution of beneficiary species ([56]), enabling species to migrate to higher altitudes ([57]). These nursery effects could be particularly intense in a context of global warming ([58]). The diversity and large size of alpine tropical plant life forms means that they could have a greater nurse effect on other species than alpine temperate nurses ([59]).

Finally, global warming in recent decades has led to a major glacial retreat in Europe and the Andes ([60]). The successful extension of the distributions of Alpine species depends on the colonisation of these new habitats. However, unlike existing habitats which are subject to secondary succession, proglacial margins are subject to primary succession where neither soil nor vegetation is present at T0. In an alpine environment, soil development is very slow ([61]). In these environments, it has been shown that colonising plants are mainly dispersed by the wind and that nursery plants are absent or insufficiently mature to accelerate succession ([62]). Comparing the responses of plant species in temperate and tropical latitudes using a common protocol that tests the variables 'snow cover', 'nursery plants' and 'soil development' is likely to enrich the theoretical framework of alpine ecology in the face of global change.

Figure 1 – *Deyeuxia Ovata* sur un glacier

Figure 2 – Glacier qui fond :'(

Root-stem interactions in trees under climate change. Applications for ornamental tree nursery production.

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	Claire Atger (Consulting firm 'Pousse conseil')

| **Funding** | ANRT (CIFRE), BRL Espaces Naturels, CIRAD |

Keywords : root – shoot interactions, root system, root pruning, tree growth, growing conditions, architecture, urban tree, nursery, climate change.

Planting trees in urban areas often results in a poor establishment, leading to many failures [63]. This is explained by the harsh growing conditions in urban areas (especially with regard to the soil conditions ; [64]), but also by the production systems in the tree nursery industry [65, 66]. Indeed, the growing conditions of trees in nurseries are far from those that will be encountered in urban areas. In addition, trees are often damaged by repeated high-intensity pruning of roots and shoots (Fig. 1). Finally, the aerial part of the tree is often oversized compared to the root system (Fig. 2).

The aim of this PhD project is to study the impact of different production systems in the nursery (usual methods versus alternative methods) on establishment and resilience to fluctuations in water supply after transplanting.

However, the root system is a key driver to establishment after transplanting.

Can we improve the establishment of urban trees 1) by producing young trees in nursery under growing conditions that are closer to those of urban planting sites, and 2) by managing the deployment of the root system to restore a root/stem balance ?

We hypothesise that the production of young trees in harsh soils with limited irrigation should allow the trees to develop a more consistent root/shoot ratio improving the establishment. We also assume that cutting the root system early, when the roots are still thin and young, will favour its division and limit the impact when the tree will be uprooted and transplanted into an urban area.

To test these hypotheses, we have planted young hackberry trees (*Celtis australis*) at the *BRL Espaces Naturels* nursery (Gard region, France) under different growing conditions (different soil profiles and water regimes) and intensity of root pruning. Since planting, the tree growth is monitored under each treatment.

To study the interactions between root and shoot systems in relation to the environment, the thesis is divided into the four following research areas :

- Links between stem and root growth after planting
- Relationships between spatial heterogeneity of growth and soil characteristics
- Structuration of the root system for uprooting by circling the roots and its effects on growth
- Root-stem balance under reduced irrigation and its effects on resilience to fluctuations in water supply

After the first growing season, we observed a significant gradient in annual shoot production in terms of number of shoots, shoot growth dynamics, functioning time and leaf area (Fig. 2). We uprooted and characterised 83 individuals to identify the relationships between stem and root regrowth. We have shown that these indicators can be used to assess both regeneration and health of the root system (Fig. 2). Spatialisation of the growth variables within the plots has enabled to identify areas of high *versus* low growth. This suggests that stem growth is a reflection of restrictive conditions and/or limited soil resources. In order to identify the limiting factors for tree growth, we opened soil pits in these areas, and we are studying the physical and chemical properties of the soil. To prepare the root system to uprooting, we have cut the roots by a full *versus* half circling at the end of the first growing season. In the second growing season, we observed a strong impact on fully pruned trees (reduced shoot production, leaf area, trunk growth), while the differences are slight or not significant between partially pruned and unpruned trees. Excavations are needed to examine how the root systems have been structured following full or partial circling.

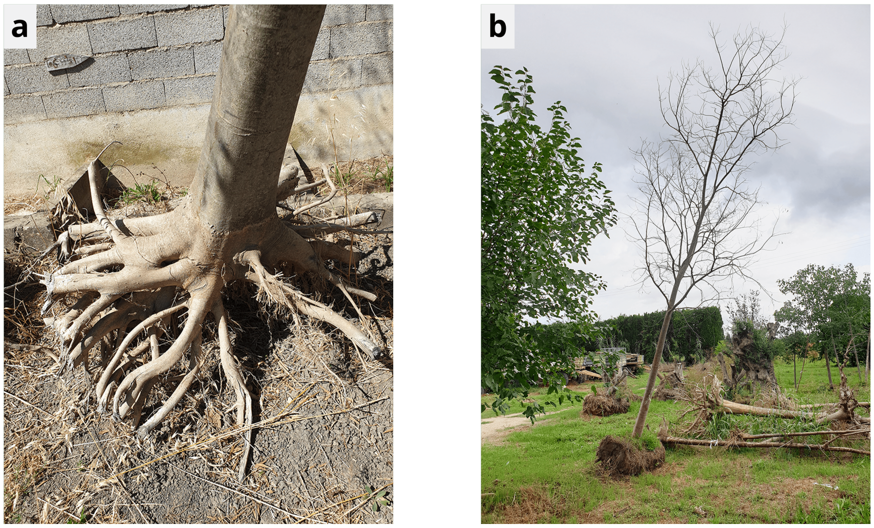

FIGURE 1 – a. Root system damaged by extreme pruning. b. Oversized aboveground structure in relation to the root system.

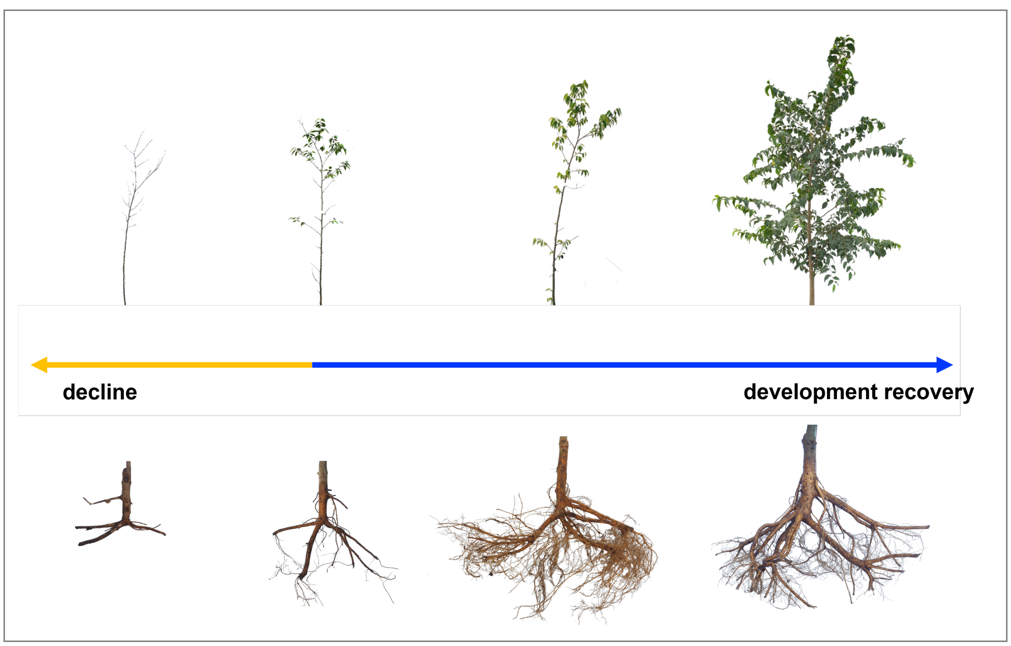

FIGURE 2 – After planting, we observe a gradient in annual shoot production in terms of number and length of shoots, shoot growth dynamics, functioning time and leaf area. From left to right : tree still alive but which has not regrown, tree with a late recovery that has developed epicormic shoots while some axes have died in the crown, tree with a rapid recovery but which has only produced monocyclic shoots, tree with a rapid recovery wich produced numerous polycyclic shoots. For each of these categories, the characteristics of the shoots are linked to the state of regeneration and the health of the root system.

The use of multitemporal lidar to monitor the impact of climate change on tropical forest C sink

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Funding Université de Montpellier

Keywords : ALS lidar, Carbon sink, Biomass, allometric equation, Aboveground biomass

The intact tropical forest carbon sink appears to have peaked and its saturation and continued decline have implications for policies aimed at stabilising the Earth's climate. Although they remain a major carbon sink tropical forests' capacity to absorb additional carbon seem to be diminishing.

While tropical forests may be more directly threatened by deforestation and degradation, the future carbon balance will also be affected by climate change and forest restoration initiatives.

Trends in tree mortality in tropical forests are driven by the interplay of altered patterns of rainfall, temperature and wind regime accompanying climate and the fertilization effect of increased carbon dioxide concentration levels in the atmosphere.

To better understand drivers of current forest dynamics, we propose to leverage an exceptional dataset of coincident ground-based forest inventories and ALS scans covering a range of tropical forests physiognomy and spanning over a decade.

In this study, we will use repeat LiDAR to characterize not just the structure of forests, but also the aboveground carbon dynamics in relation to forest composition and environmental context. This should help produce guidelines to better manage and safeguard these vital ecosystems by gaining insight into how vast, inaccessible forests are faring in the face of accelerating global climate change.

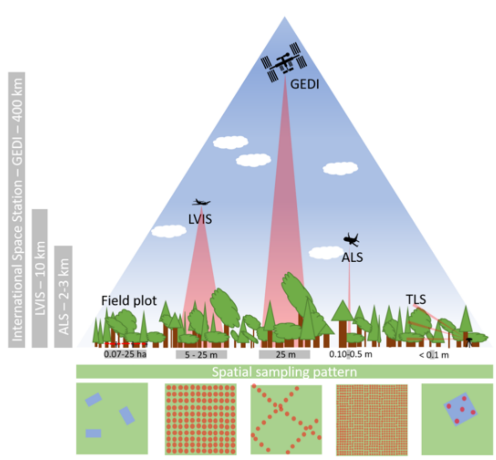

Figure 1 – Forms of different types of LIDAR data collection

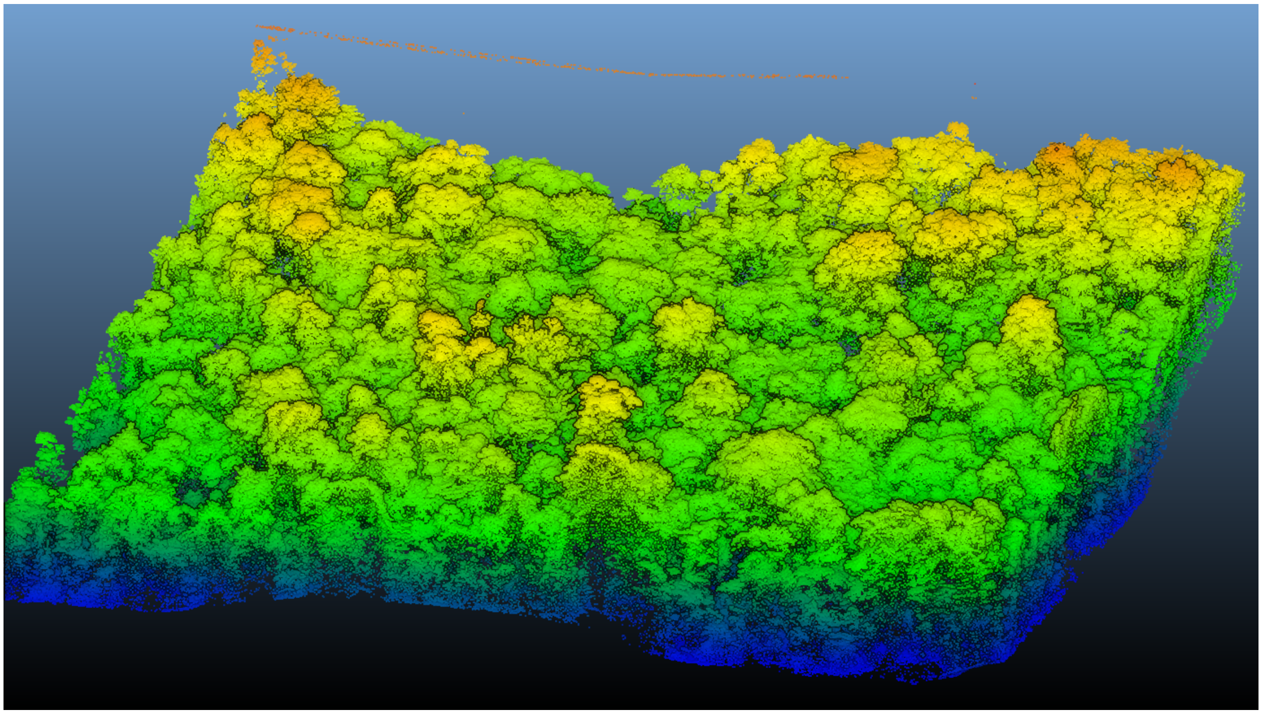

FIGURE 2 – Side view of forest point cloud data

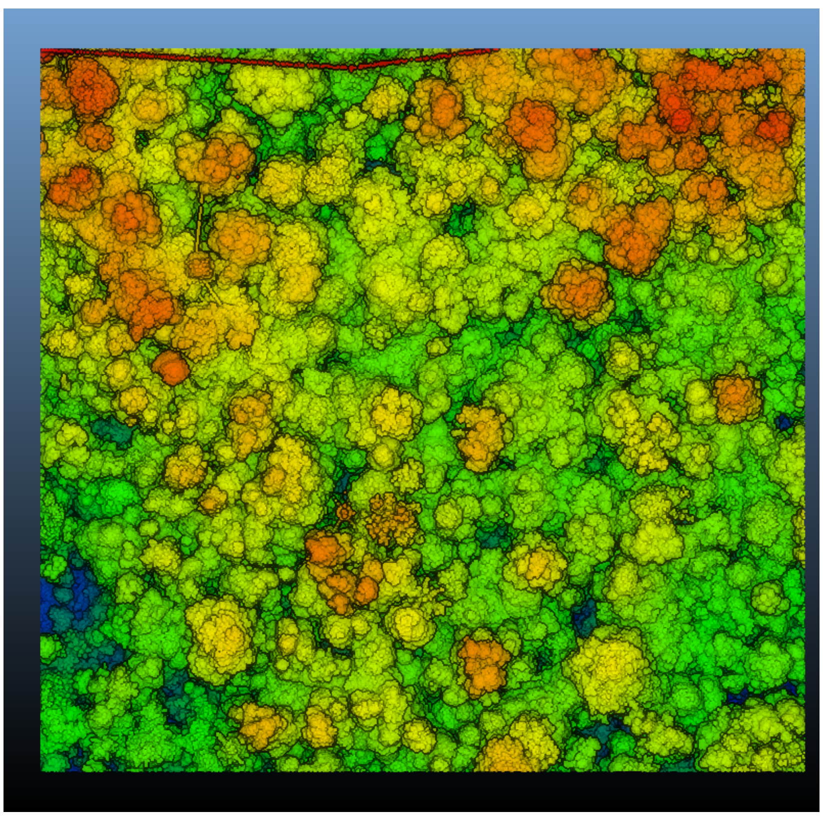

FIGURE 3 – Aerial view of the forest point cloud

Modelling of soil carbon dynamics in temperate forest ecosystems

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Funding	FISSA, ANR project

Keywords : Soil carbon, forest soil, temperate forest, Bayesian statistics

Although France has various models to predict the evolution of forest stands under the effect of climate change, there is currently none validated that can be deployed throughout European France to estimate the dynamics of organic matter and its carbon (C) in forest soils, whichever are the species and stand management.

In forest ecosystems, Yasso is one of the best-known models that predict soil C dynamics. This model may be appropriate given (i) its granulometry adapted to regional and national scales, (ii) its simple structure, and (iii) its measurable compartments (five deriving in part from chemical extraction). It is calibrated with data distributed globally, but its reliability for given French temperate forests has proven to be uncertain, notably due to the great diversity of species, soils, climates and stand managements. An evaluation of this model for forest soils in France confirmed its usefulness to estimate the evolution of C, but it cannot be used to simulate the later in the future in the considered version, because (i) the biochemical input data of litter and forest soils are not available, (ii) the model was adjusted by considering all flows between compartments were possible, but recent mechanistic research show that some are not relevant, (iii) the soil properties are not taken into account in the model, yet these have an impact on the soil C dynamics in a temperate environment, and (iv) the flux of fine roots remains difficult to estimate and can lead to a systematic bias in the simulations. A new version of the model has been released, with removed flows, but still including biochemically implausible ones.

The objective of this PhD is to predict the evolution of C in French forest soils considering management, soil, and climate. The research questions derive from a previous evaluation of the model : RQ1 – Does the new Yasso version offer substantial improvements over the previous one ? ; RQ2 – How to redefine the flows between Yasso biochemical compartments, and integrate soil processes not currently included in Yasso ? ; RQ3 – How these modifications can improve plot-to-plot predictions after recalibration, and is there a soil effect in the model residuals, after taking into account the litter quantity and the biochemistry ? ; RQ4 – If yes, how to consider this soil effect, and on which flows between compartments ?

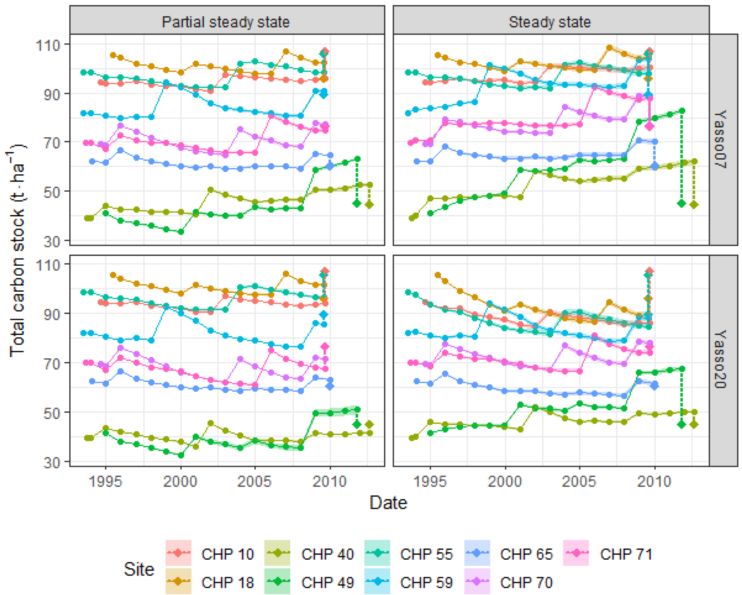

FIGURE 1 – Predictions of the total carbon stock (t·ha^{-1}) from the Yasso07 (top) and Yasso20 (bottom) in pedunculate oak stands, given two initial stock settings (left : partial steady state ; right : complete steady state). The circles and lines represent the models' predictions, with the shaded area showing the highest density interval (95%). The diamonds represent the measured stock, and the dashed lines the difference between this stock and the final prediction.

Analysis of sea-mangrove coastline fluctuations for coastal vulnerability and carbon sequestration assessments. Multi-scale and multi-decadal modeling approach of the influence of hydro-sedimentary and climatic processes in French Guiana.

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Funding	ADEME / DGTM (French Guiana)

Keywords : landscape evolution modelling, coastal mangrove, coastal vulnerability, carbon sequestration, French Guiana, Marine Copernicus, remote sensing

The Guianese mangroves occupy 68% of the total area of mangroves in the French overseas territories. On a particularly unstable Guianese coastline, they can develop extensively and with a great dynamic of forest biomass. In a rapidly growing department where 80% of the population lives on the coast, it is urgent to assess the future and potential of these coastal forests in a context of climate change. This thesis project will examine the influence of hydro-sedimentary and climatic processes on mangrove extension using a modeling approach that simulates sea-mangrove coastline fluctuations and compares them to observations from a unique spatial database (70 years of monitoring). The respective influence of waves and ocean current regimes on the Guianese mangroves can thus be evaluated in various sedimentary contexts and over several decades. The maintenance capacity of mangroves will be tested, locally and regionally, through simulations that involve realistic scenarios of oceanic and climatic forcing (e.g. winter storms in the North Atlantic Ocean). This better understood capacity to maintain and renew Guianese mangroves will be used (notion of nature-based solutions), on the one hand, to help predict the vulnerability of the Guianese coastline to erosion and siltation and, on the other hand, to propose a framework for analyzing and monitoring carbon sequestration by mangroves.

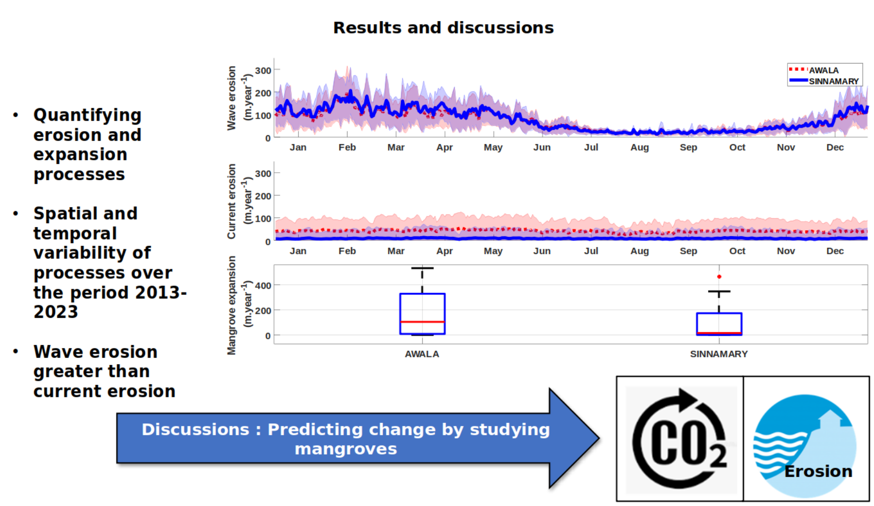
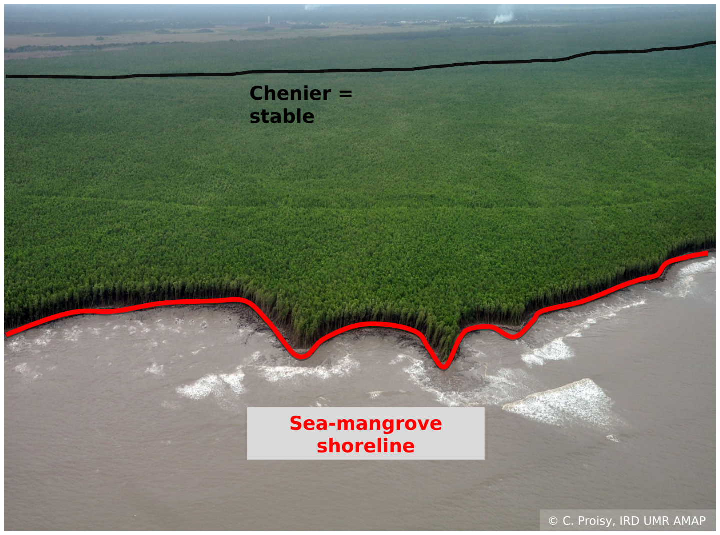
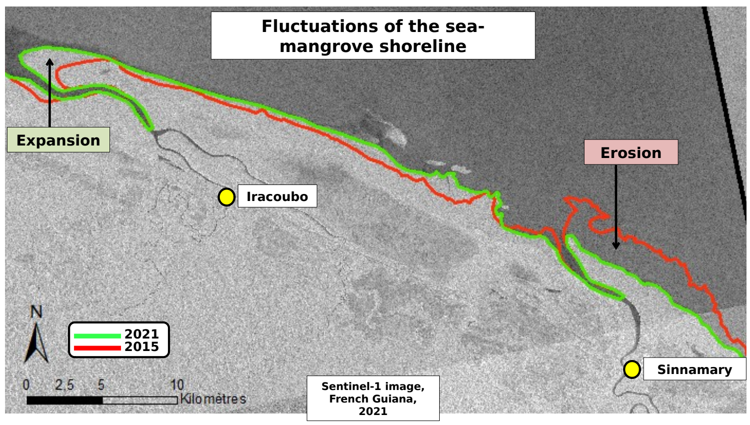
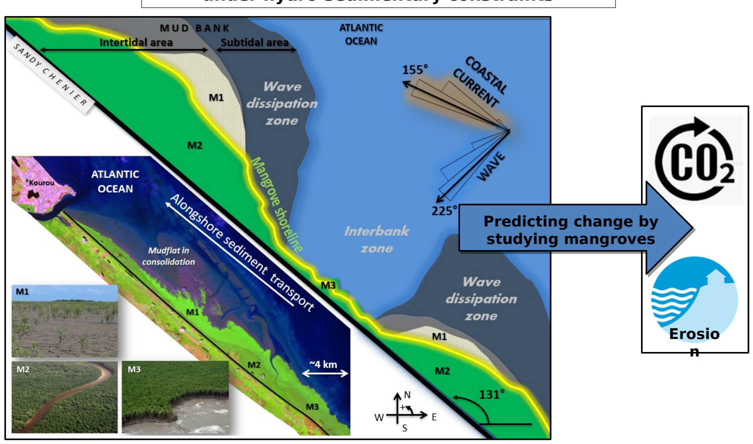


Figure 1 – Results and discussions





To find these fluctuations by a modeling approach of the dynamics of the landscape under hydro-sedimentary constraints



Impact of anthropization on vector community dynamics : modeling, analysis and simulation. Control of epidemiological risk in peri-forest context in Cameroon.

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Funding	Institut ExposUM

Keywords : Mathematical Modeling - Population dynamics – Metapopulation - Mathematical epidemiology – Correlative Models – Mechanistic Models – Control - Qualitative Analysis - Numerical Simulations.

In Central Africa, population growth is accompanied by a growing demand for resources, leading to many changes in forest and agricultural landscapes. This human pressure manifests itself not only in the fragmentation and degradation of vegetation, as well as in the loss of biodiversity, but also in changes in the populations of disease-carrying animals, which can promote the emergence of zoonotic diseases and diseases transmitted by vectors such as mosquitoes. It is therefore essential to better understand the interactions between vectors, vegetation and hosts to assess the positive or negative effects of this anthropization, and to set up a framework for joint action enabling to limit negative effects and to ensure the long-term future of positive ones.

In order to embrace all those aspects, an interdisciplinary project has been funded by the institute ExposUM. This project, named I-CARE (for ImpaCt de l'Anthropisation sur le Risque d'Emergence d'arboviroses zoonotiques en Afrique Centrale), involved 3 research units (MIVEGEC, INNOVATION, and AMAP). It is structured around three theses in Entomology, in Economy and in Applied Mathematics.

Mathematical modeling is essential to integrate all the processes involved, in order to better target experiments and observations in the field, to confirm or refute scientific hypotheses, and to evaluate, through mathematical analysis and simulations, the evolution scenarios of these systems to aid decision-making. Finally, control strategies will be studied to mitigate the epidemiological risk to populations, while preserving biodiversity.

Through field studies and theoretical studies, the main objectives of my thesis will be :

- Synthesize/Integrate the interactions between Vegetation, Mosquitoes and Human into mathematical models, in collaboration with I-CARE experts and other PhD students involved in I-CARE.
- Analyze and simulate, using reliable numerical methods, these mathematical models. Discuss the results with I-CARE field experts.
- Implement ongoing control strategies, describe by I-CARE experts and PhD students. Propose new control strategies, known to be optimal through mathematical analysis. Discuss their pertinence and feasability with I-CARE experts.

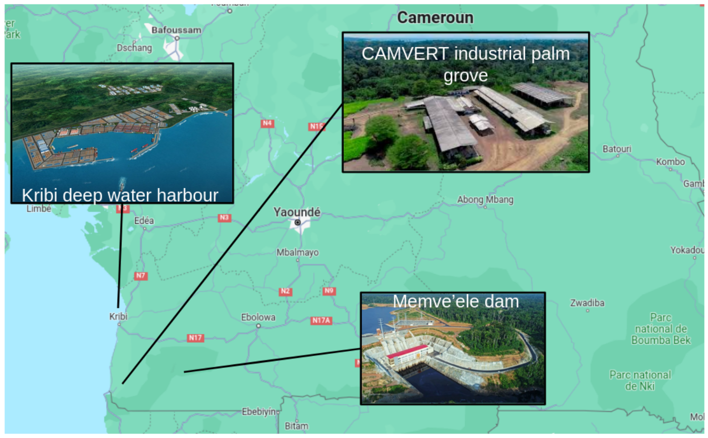

FIGURE 1 – Geography of the I-CARE project in southern Cameroon and illustrations of the main man developments

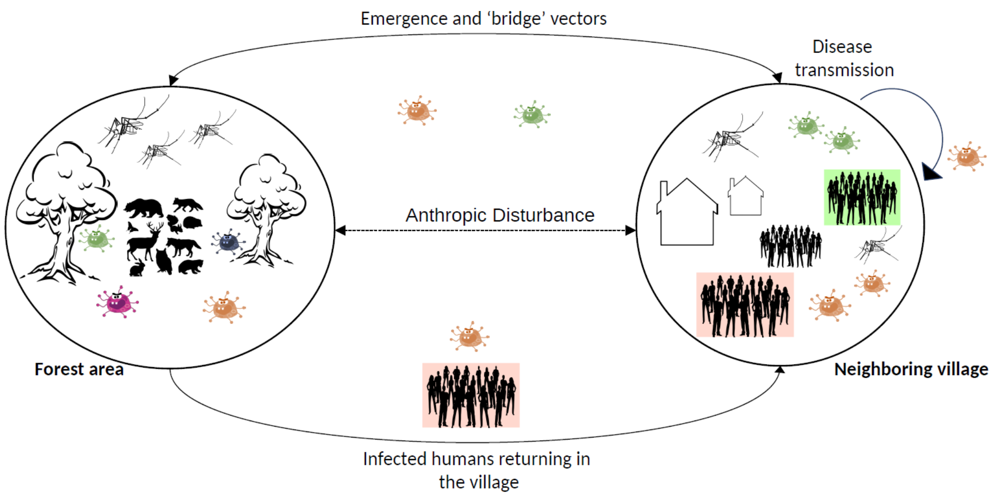

FIGURE 2 – General framework of the PhD

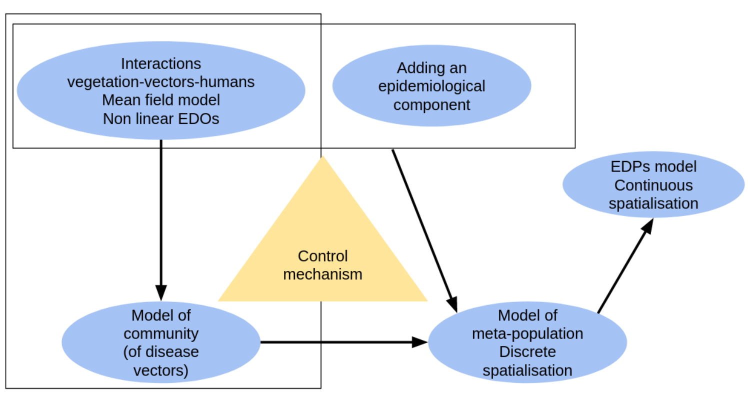

FIGURE 3 – Methodology of the PhD

Impact of harvesting on the dynamics of wild plant populations

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Funding Organisme Français de la Biodiversité (OFB) et Université de Montpellier

Keywords : Conservation - Distribution - Wild plant harvesting - Species distribution modelling - Conservation priorities - Ethnobotany

Gathering wild plants for commercial purposes is an age-old practice whose modalities vary according to cultures, eras and the biological characteristics of the collected plants. Its sustainability depends on the persistence of these populations. However, resource renewal depends on the combined action of environmental factors and harvesting pressures, which can alter population dynamics. Scientific studies on these issues are still rare, as the human footprint is a complex factor to integrate into demographic monitoring.

Nevertheless, with the recent increase in wild plant consumption, the development of protocols and studies of plant species subject to gathering is becoming an important topic for biodiversity conservation. Setting up a regulation for wild plant gathering also requires a general assessment of the distribution of the resource over the territory. Indeed, defining a strategy for exploiting a resource requires analysing its availability, to better distribute harvesting pressures.

A spatialised approach, through plant abundance distribution models, provides an opportunity to test automated approaches for characterising these distributions. However, these methods, which are still experimental, need to be improved. Indeed, the climatic variables commonly used to model large-scale distributions often prove uninformative for understanding population biology, which requires other environmental variables and more restricted scales of study. Firstly, the use of fine-scale climatic variables (<100m) enables a better understanding of the microclimatic conditions allowing species to develop. Secondly, the integration of vegetation indices, calculated via satellite images, helps to describe local plant dynamics. Finally, the integration of soil and topographical variables adds to the understanding of local ecological structures. Ultimately, the relative importance of these variables and their interactions could lead to a better characterisation of resource abundance.

With this in mind, I seek to study, in collaboration with the Conservatoires Botaniques Nationaux (CBN) and the Association Française des professionnels de la Cueillette (AFC), the implementation of monitoring protocols for species currently subject to foraging. These methods will hopefully lead to a better understanding of the conservation status of plant populations, and subsequently adapt resource management programs. These questions will be addressed jointly with stakeholders in harvesting and nature conservation, such as the OFB or Nature Parks. The goals of the project are 1. to improve knowledge of wild plant gathering, through an inventory of current gathering practices, 2. to quantify the resource on a regional level using occurrence and abundance models, and 3. to develop a local monitoring of gathering impacts.

FIGURE 1 – Picking thyme with a sickle - Angela Bolis

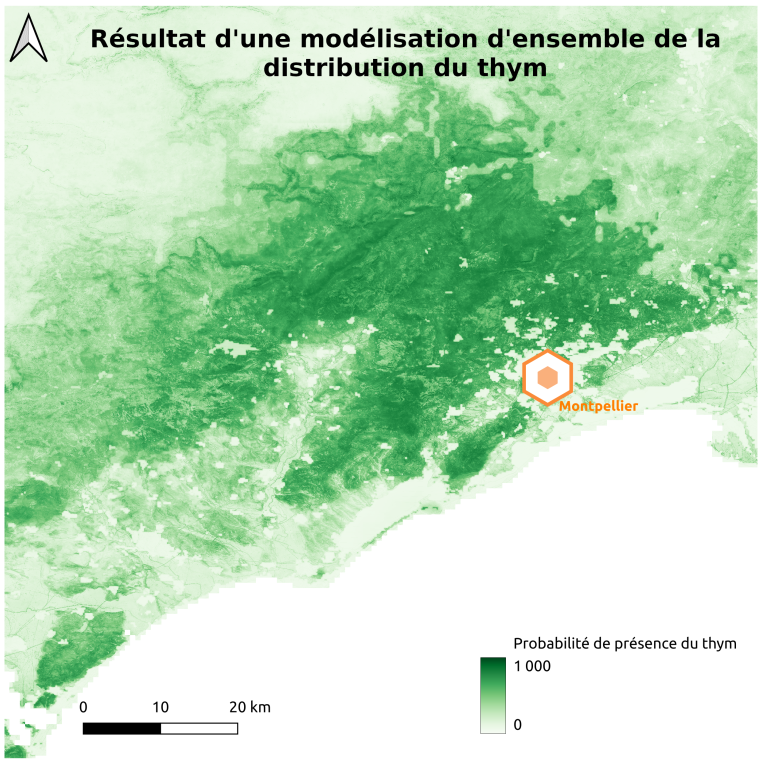

FIGURE 2 – Modeling the distribution of thyme near montpellier

Ecological strategies of central African lianas : From Macro-Anatomical Diversity to Community Patterns

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Funding	CIRAD & GROWBOT project

Keywords : woody vines, canopy, competition, UAV systems, remote sensing, functional traits, tropical forests, DYnAfFor, leaf economic spectrum, wood economic spectrum

Lianas develop some of the most complex vascular organizations in plants and are an emblematic growth form in the diversity and dynamics of tropical forests. However, their ecology and especially the links between traits, anatomy and community structure remain poorly known. The goal of this thesis is to deepen our understanding of the ecological strategies of lianas, from macroanatomical diversity to community-level patterns, using both ground- and drone-based field data. The study was carried out in Northern Congo, where trees and lianas are monitored in permanent plots through time. In three independent chapters, I explore (i) the link between commonly used ground-based liana measurements and drone-based measurements of liana leaf coverage over tree crowns ; (ii) the influence of local topography, forest structure, and tree composition on liana community structure and floristic and functional composition ; and (iii) the strategies associated with the macroanatomical diversity of lianas, their links to the leaf economic spectrum, and their patterns across a phylogeny and environmental gradients. Most ground-derived liana metrics were significantly related to drone-derived liana leaf coverage over tree crowns. This was best predicted by liana basal area and negatively mediated by liana wood density, with a higher leaf area-to-diameter ratio for light-wooded lianas (see [67] ; Fig. 1). Along environmental gradients, the liana community structure was mainly determined by local forest structure, with an increased abundance of small-sized lianas and basal area in open canopy areas where they competed with giant herbs. The floristic and functional composition of lianas varied marginally along these gradients. Faster acquisition strategies tended to occur in open canopy areas (low liana wood density, high specific leaf area, and %PO4). Lianas exhibited significant species-specific associations with the most common lianas and trees. Through the lens of functional ecology, liana species exhibited a wide diversity of macroanatomical structures and cambial variants. These were associated with strategies ranging from hydraulic efficiency to hydraulic safety, and higher density stems in the self-supporting phase to resilience during climbing (Fig. 2). Both leaf and wood strategies were significantly coupled (Fig. 3) and distributed throughout the phylogeny. However, only the trade-off between acquisitive and conservative leaf strategies was significantly affected by environmental gradients, while wood strategies appeared to remain neutral. I hope that this work will contribute to a better understanding of the temporal and spatial distribution of liana species and better predict shifts under large-scale and environmental conditions.

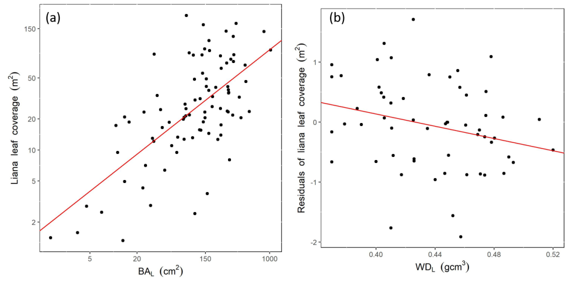

FIGURE 1 – Relationship between total liana basal area measured from the ground and leaf coverage estimated from drone data for 87 tree crowns (a). The red line illustrates the predicted linear log-log model. Axes are shown in log scale. Relationship between the basal area weighted liana wood density and the residuals of the selected linear model predicting liana leaf coverage from total liana basal area (b). The red (significant slope) line illustrate the predicted linear model between the two variables.

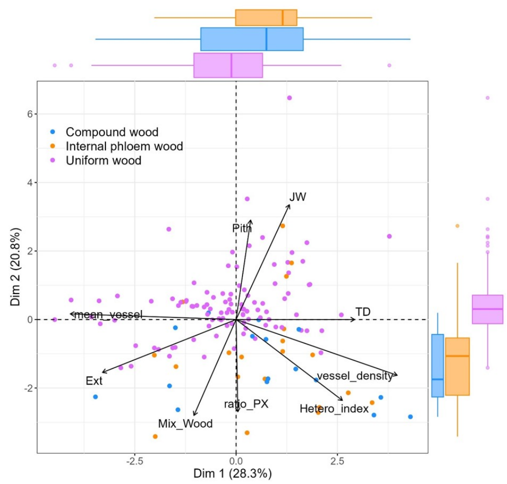

FIGURE 2 – Plan 1-2 of a Principal Coordinate Analysis performed on anatomical functional traits. Cambial variant wood categories ; uniform, internal phloem and compound woods ; are represented in pink, orange and blue, respectively. Boxplots illustrate the differences between the scores of cambial variant wood categories along the two first PCA axes.

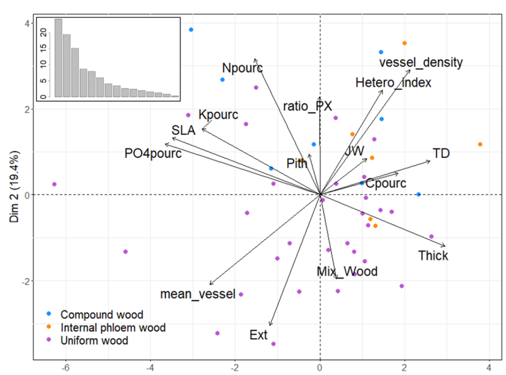

FIGURE 3 – Plan 1-2 of a Principal Coordinate Analysis performed on leaf and stem functional traits of 46 liana species with cambial variant wood categories ; uniform, internal phloem and compound woods ; are represented in pink, orange and blue, respectively.

Abbreviations for Fig. 2 and 3 : Pith : pith area ; JW : juvenile wood area ; Ext : external tissues area ; Hetero index : Tissue heterogeneity index ; ratio PX : phloem/xylem ratio ; TD : tissue (wood) density ; vessel density : mean wood vessel density, mean vessel : mean wood vessel area ; Thick : leaf thickness ; SLA : Specific leaf area, %C : foliar carbon ; %N : foliar nitrogen ; %PO4 : foliar phosphorus ; %K : foliar potassium.

Interaction between pest attacks and plant growth using a model approach applied to robusta coffee in Uganda. Effects on the production

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Funding	$\frac{1}{2}$ CIRAD $\frac{1}{2}$ EU DESIRA ROBUST project

Keywords : modelling, agronomy, applied mathematics, pest and disease, crop production, simulation, integrated model, FSPM, statistics

Agroecological transition is a rapidly developing field of research and development that aspires to enhance the efficacy of agronomic systems through the employment of intricate systems modelling. This process entails a comprehensive analysis of production processes to identify potential interactions within the system [68]. The aim of this thesis is to assess how pests and diseases (P&D) impact crop production, including the mechanisms at the plant and crop scales, as well as the effect of crop practices on production.

The estimated effects of P&D on plants are considered to result from interactions between dynamic models : the plant growth model (considered at least at the organ scale), the P&D model, and the possible addition of a human intervention model (treatment, harvesting...).

To determine more precisely the thresholds at which P&Ds are likely to have a significant economic impact on production [69], and to make an appropriate treatment decision, a coupled model operating over the long term is necessary.

Such a model could provide a more accurate estimation of the effects of climate change on plant phenology/biotic development. One interesting field where we can apply this coupled model is Uganda. It has experienced a great resurgence of pests and diseases in coffee tree fields [70], [71] despite the important efforts of national institutes to create resistant clones, especially for coffee wilt disease (Fusarium xylarioides). In addition, climate change induces new environmental conditions impacting plant growth dynamics as well as the dynamics of pathogens and insects [72, 73, 74]. Consequently, the coffee berry borer (CBB) (Hypothenemus hampei) and coffee leaf rust (CLR) (Hemileia vastatrix) ; are present in Uganda, although at moderate levels. However, severe cases of red blister (RB) (Cercospora coffeicola) which affects berries, of black twig borer (BTB) (Xylosandrus compactus) [75] and of coffee wilt disease [76, 77, 78] are now reported.

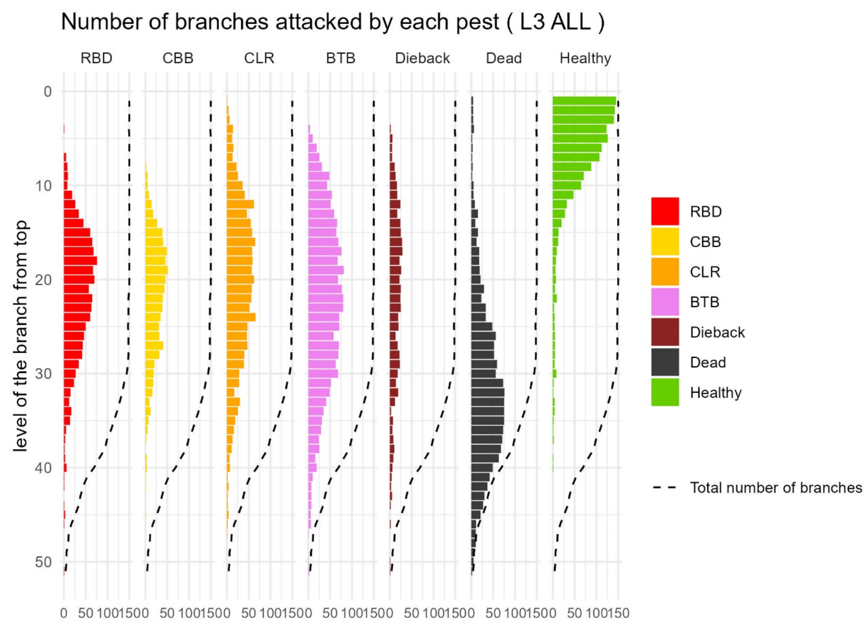

FIGURE 1 – Number of branches attacked by different pests (RBD, CBB and BTB) disease (CLR) and their state on a set of 75 coffee trees (L3 Clone from Uganda)

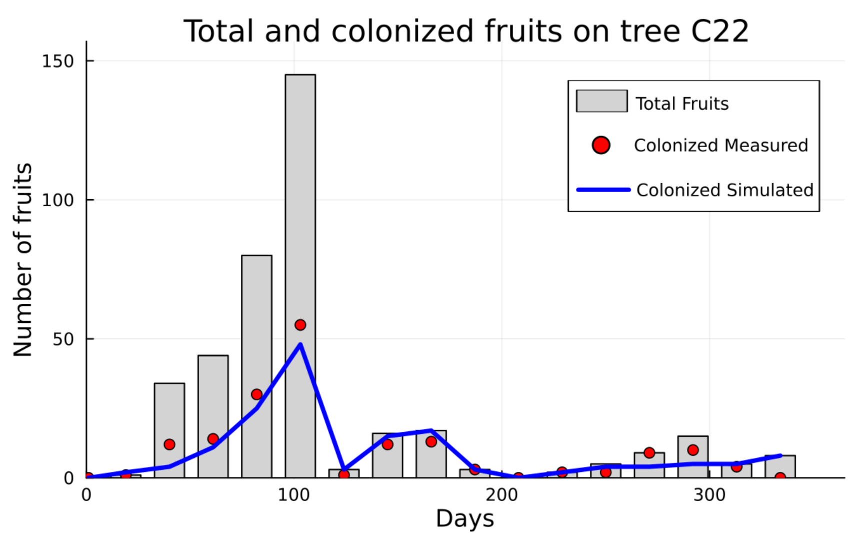

FIGURE 2 – Simulation results compared to field data on a coffee trees in Indonesia. Points represents the recorded number of harvested fruits colonized by CBB on 6 fruiting branches of the tree. Lines represents the results of the simulation by MIMIC at the same date as the observation. Bars represent the total recorded harvested fruits (healthy and colonized) [79]

Marantaceae forests spatio-temporal dynamics in Central Africa

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Funding	ANR DESSFOR

Keywords : Marantaceae, tropical forest, North Congo, alternative stable state

Marantaceae forests are a little-known but widespread forest type in central Africa. They form large forest patches with an open tree canopy and an understorey composed of a dense and continuous cover of giant herbaceous plants of the order Zingiberales (including Marantaceae) where tree regeneration is low ([80] ; [81]). This results in low floristic diversity and a low carbon stock in comparison to mature dense forest ([82]). Moreover, it seems that Marantaceae forests are stable in time, some of them being 1000 years old ([83, 84]).

They would then represent a state of stopped vegetation succession following disturbances in dense forests. However, except for two thesis, scientific literature on the subject remains limited, not very accessible and mainly descriptive. Thus, the widespread presence of Marantaceae forests in the Congo Basin and their potential arrested succession status makes them an excellent case study of alternative stable state, an ecosystem dynamic difficult to demonstrate in nature.

My thesis aims to understand the external factors and ecological mechanisms that drive the maintenance and extension of Marantaceae forests. It is structured in four chapters, from the landscape scale, via the forest stand scale, to relationships between individuals :

- 1) A large-scale study of the characteristics and determinants of the main forest types distribution and composition in northern Congo, including Marantaceae forests ;
- 2) A study of the effects of fire on the dynamics of Marantaceae forests ;
- 3) A study of the effects of logging on the abundance of Marantaceae and on their reproductive strategies ;
- 4) And a study of interactions between Marantaceae and young woody plants through competition and potential allelopathy mechanisms.

To test my hypotheses, I collected a variety of data by analysing satellite image ; by organising inventories in areas disturbed by fire and logging (specific tree inventory, tree diameter $\geqslant$1 cm, giant herb density, soil chemical composition, soil seed bank, genetic information on Marantaceae leaves, etc.) ; and by creating and monitoring an experiment in a plant nursery in which Marantaceae seedlings and young woody plants grew under controlled conditions.

Among the expected results, I hope to show that Marantaceae forests form large patches within a mosaic of other forest types and that these patches are characterised by a particular structure and floristic composition. I expect that disturbances such as fire and logging contribute to the maintenance and spread of Marantaceae forests, supported by mechanisms of competition, allelopathy and a reproductive strategy based on sexual reproduction and clonality.

If my hypotheses proved to be true, the predicted increase in disturbances in the coming years with increasing climate change effects and human pressure ([85] ; [86]) will lead to a risk of Marantaceae forests spreading out within the central African tropical moist forest mosaic. It would be to the detriment of diverse forest types and the ecological services they provide, as the areas converted in Marantaceae forests would remain stable over time.

FIGURE 1 – Marantaceae forest : open tree canopy, giant herbs cover the understorey and climb to trees liana-like

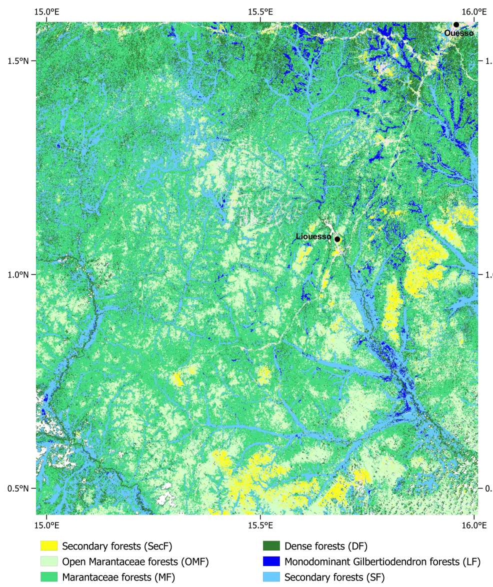

FIGURE 2 – Predicted vegetation map over the study area.

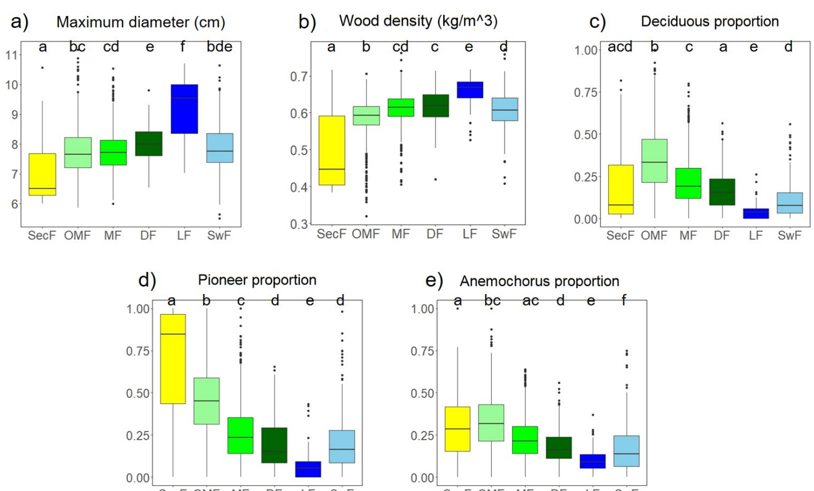

FIGURE 3 – Distribution of the community mean values of five traits among the vegetation types. SecF : secondary forests, OMF : open Marantaceae forests, MF : Marantaceae forests, DF : dense forests, LF : monodominant Gilbertiodendron forests, SwF : swamp forests. Different letter indicates significant differences (torus test on Wilcoxson effect size, $p < 0.05$).

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