

AMAPHD

2 Novembre 2021



Organisatrices :

**Jeanne CLEMENT, Asli-Begum KACAMAK,
Laëtitia LEMIERE, Camille SALMON**

Table des matières

1	Architecture and structure-function modelling of native savannah agroforestry species in Côte d'Ivoire	3
2	Mapping tropical forest diversity from hyper- and multi-spectral imaging	5
3	Architecture et variabilité interspécifique de trois espèces de <i>Baracoffea</i> : <i>Coffea boinensis</i> , <i>Coffea bissetiae</i> et <i>C. ambongensis</i> Davis & Rakotonasolo.	7
4	Predicting tree species vulnerability to climate change in the tropical forest of French Guiana using joint species distribution models	9
5	Impact des lianes sur la croissance des arbres dans une forêt du Nord Congo	11
6	Interpretability of distribution models of plant species communities learned through deep learning - application to crop weeds in the context of agro-ecology	13
7	A predictive approach to determining the joint conservation status of species	15
8	What are the consequences of different types of intraspecific variability on community dynamics ?	17
9	Functional diversity of exploratory phases in climbing plants : a static, dynamic, and modelling approach of searcher shoots to enhance bio-inspired applications in soft robotics.	19
10	Vegetation alters how soil properties and climate influence microbial activity and functional diversity in rhizosphere and bulk soil along an elevation gradient	21
11	Tracking tree mortality rate in a tropical moist forest using multi-temporal LiDAR	23
12	Ecological strategies of African lianas in stable and disturbed environments : Bio inspiring models for soft robotics	25
13	Environmental changes and structure, acquisition, and transmission of plant microbiota.	27
14	Augmented reality to facilitate agroforestry system design	29
15	Taxonomic ambiguities on <i>Silene</i> section <i>Silene</i> (<i>Caryophyllaceae</i>). : The case of <i>Silene nocturna</i> group	31
16	Utilisation du LiDAR terrestre et du Drone pour la quantification de la biomasse aérienne : cas des savanes du Centre Cameroun	33
17	Dynamique spatio-temporelle des forêts à Marantacées d'Afrique centrale	35
18	Leveraging high resolution spaceborne data to monitor tropical forests phenology	37
19	The adaptative significance of monocarpy in woody perennial plants : investigation around the genus <i>Cerberiopsis</i>	39
20	Model checking ecological state transition graphs	41

1 Architecture and structure-function modelling of native savannah agroforestry species in Côte d'Ivoire

Author	Beda Innocent ADJI
Mail	adjibedainnocent@gmail.com
Supervisors	Doffou Sélastique AKAFFOU, Marc JAEGER, Sylvie-Annabel SABATIER, Philippe De REFFYE
Keywords	Côte d'Ivoire, <i>Khaya senegalensis</i> , <i>Pterocarpus erinaceus</i> , <i>Parkia biglobosa</i> , architecture, modelling

In Côte d'Ivoire, biodiversity is threatened by deforestation, which has spread to the savannah areas. Reforestation and agroforestry based on local species are the two solutions chosen by Côte d'Ivoire to cushion and mitigate the negative consequences of this phenomenon. *Khaya senegalensis*, *Pterocarpus erinaceus* and *Parkia biglobosa* are three indigenous savannah species that are overexploited and threatened by rural populations for their multiple uses. Their integration into reforestation and agroforestry programmes is a solution for their conservation and sustainable use.

The objective of this study is to understand the functioning of the three species and to optimise their cultivation in Côte d'Ivoire. Therefore, a series of germination tests were undertaken in different environments in order to evaluate their adaptability and their potential for sexual reproduction. An architectural study from seedling to adult tree was carried out along an ecological gradient in order to determine the architectural development sequence of three species and to identify priority areas suitable for the establishment of permanent plots. Finally, the collection of dimensions and biomass of phytomeres and growth units of individuals aged 6, 12 and 24 months in the Multiscale Trees Graph format in the nursery allowed the modelling of meristem function, development and growth of the target species.

The results showed that the dendrometric characteristics of the seeders are negligible criteria for sexual regeneration ($P > 0.05$). Maternal environment and seed size are important selection tools and criteria for obtaining good germination and vigorous seedlings ($p < 0.05$). *Khaya senegalensis* is a 5-order branching tree with 4 axis categories and follows Rauh's architectural model. *Pterocarpus erinaceus* and *Parkia biglobosa* have up to 6 orders of branching due to several reiterated sympodial structures forming arches and 3 axis categories. *Pterocarpus erinaceus* follows the architectural pattern of Troll while *Parkia biglobosa* follows the pattern of Champagnat in young stage and Troll in adult stage. The level of organisation of the three species is 5 : the phytomer, the growth unit or module, the axis, the architectural unit and the whole tree (repeated complex). The morphology of the growth units indicated difficulties in the development of species in the north of selected gradient (Ferké, Korhogo and Niakara) and favourable and priority areas for the implementation of reforestation and agroforestry programmes in the south of gradient (Daloa, Toumodi, Bouaké and Katiola). Modelling of meristem function showed that the distribution of phytomeres within growth units and the distribution of growth units along the axis are fit to an approximate fish law with a positive binomial (preformed part) and a negative binomial (neoformed part). The results showed that the topological development parameters (chronological age : N, branching probability : A, stem development probability : P, stem Bernoulli : $P = 1 - v/m$, branch development probability : B, rhythm report : W and phyllochrone) are higher in humid zone (Daloa) than in dry zone (Korhogo). These results lead to a computational plant model of the three species adapted to needs of agroforestry from a new angle in Côte d'Ivoire and to new agronomic and forestry applications.

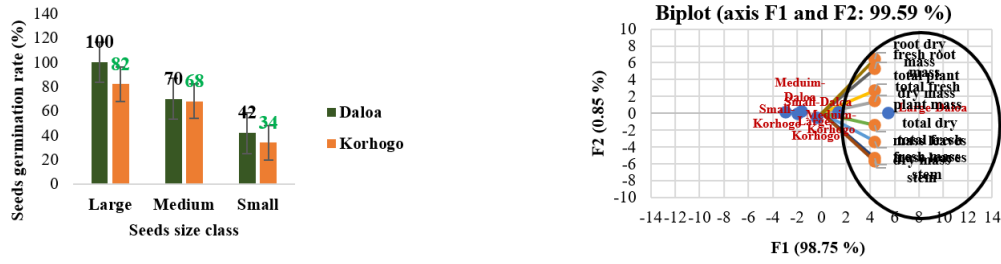


FIGURE 1 – Study site and seed size influence on germination (a) and seedling growth (b)

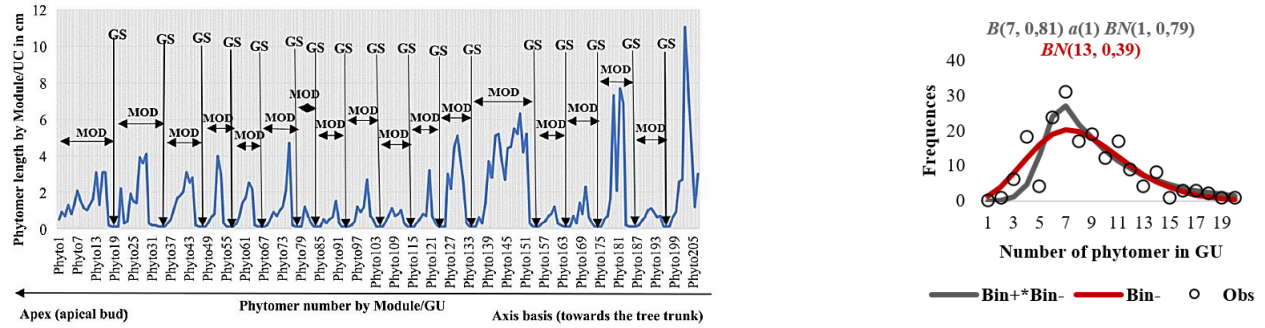


FIGURE 2 – Variation of growth units along the axis (a) and their fit to the binomial distribution (b)

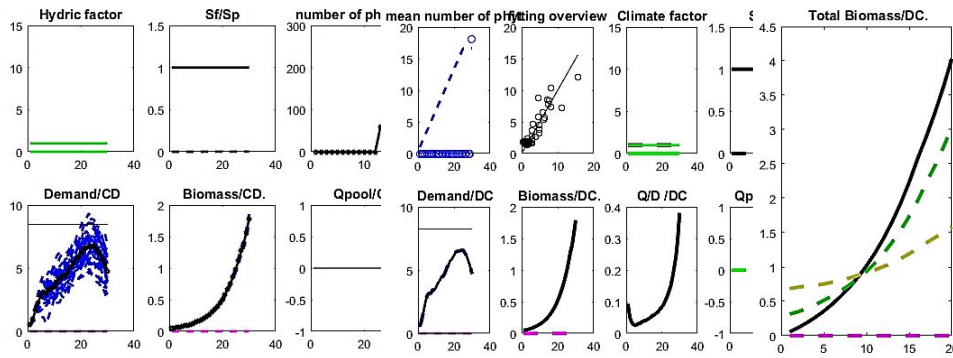


FIGURE 3 – Source-sink organ relationship in 6-month-old plants in Daloa (a) and Korhogo (b) in *P. erinaceus*

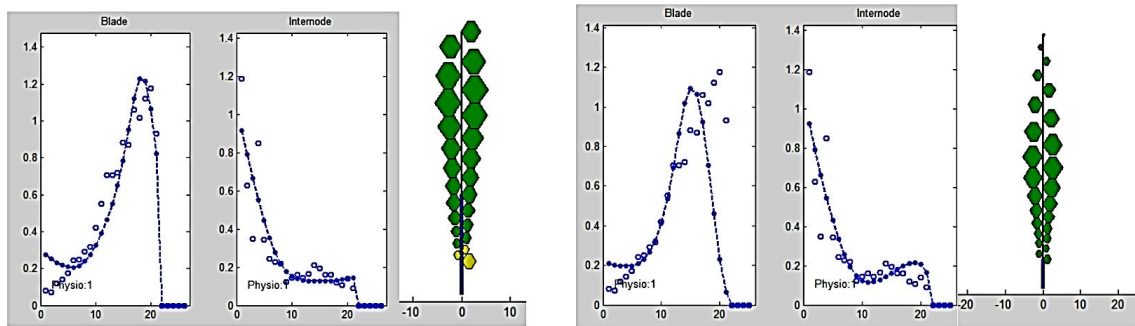


FIGURE 4 – Organic series of organs constitution in *K. senegalensis* in Daloa (a) and Korhogo (a) at 6 months

2 Mapping tropical forest diversity from hyper- and multi-spectral imaging

Author	Colette BADOUDINE
Mail	colette.badourdine@cirad.fr
Supervisors	Raphaël Pélissier, Grégoire Vincent, Jean-Baptiste Féret (UMR TETIS)
Funding	Cofinancement IRD et CNES
Keywords	Hyperspectral ; LiDAR ; tropical forests ; modeling

Tropical forests, and more specifically the Amazon rainforest, are one of the main reservoirs of biodiversity ([1]). They are the subject of an increasing interest given the rapid loss of biodiversity due to climate change, land-use change ([2]) and anthropogenic pressure ([3]). Developing monitoring systems able to assess tropical forest degradation in terms of carbon stocks and biodiversity is a challenge. The scale and speed of change in tropical forests far outstrips our ability to monitor them through forest inventories alone, which cannot be representative of the biodiversity of tropical rainforests on their own and which are costly in terms of time, human resources, and, therefore, are best suited to monitoring small areas. Developing new remote sensing approaches capable of providing rapid estimates of biodiversity over large areas is now necessary to better understand the structure and functioning of tropical rainforests in order to carry out operational monitoring of these high biodiversity areas. The use of hyperspectral sensors has shown great potential for detecting changes in the floristic and functional composition of temperate and tropical forests and estimating their biodiversity ([4],[5]).

The data available from the Paracou experimental site, which combine a regular forest inventory over 125 ha and hyperspectral images, offer the possibility of quantifying the link between spectral diversity and taxonomic diversity at different scales. We can thus measure precisely the part of spectral diversity explained by species (inter-species diversity) and by individuals (inter-crown diversity within species). Thanks to the botanical inventory on the Paracou site and the mapped and identified tree crowns, it is possible to evaluate the share of spectral variability within the crowns (intra-crown spectral variance). Based on the simulation of artificial populations with different compositions, richness and equitabilities, the importance of the taxonomic signal in the total spectral variance can be evaluated, which will allow to test the relevance of the previously described methods. This will allow us to quantify the link between spectral diversity and taxonomic diversity on different cases of real diversity, in order to answer the question : how much of the real taxonomic diversity is attributed to the spectral diversity measured on a hyperspectral image at high spatial resolution in the study of a tropical rainforest ?

We aimed at quantifying the link between spectral diversity and taxonomic diversity. To explore a large range of taxonomic diversity and composition, we generated a set of artificial populations by resampling our original dataset.

For each simulated population, we calculated a) spectral variance indices, b) three taxonomic biodiversity metrics, Richness (S), Simpson's index (D) and Shannon's index (H') and c) one evenness metric, Pielou's index (J'). We also computed total spectral variance and partition the variance into inter-species variance, inter-crowns within species variance and intra-crown variance.

The results of the regression between spectral variance and taxonomic diversity indexes shows that the taxonomic signal present in the reflectance data can be approximate by variance when selecting the spectral bands important for species discrimination.

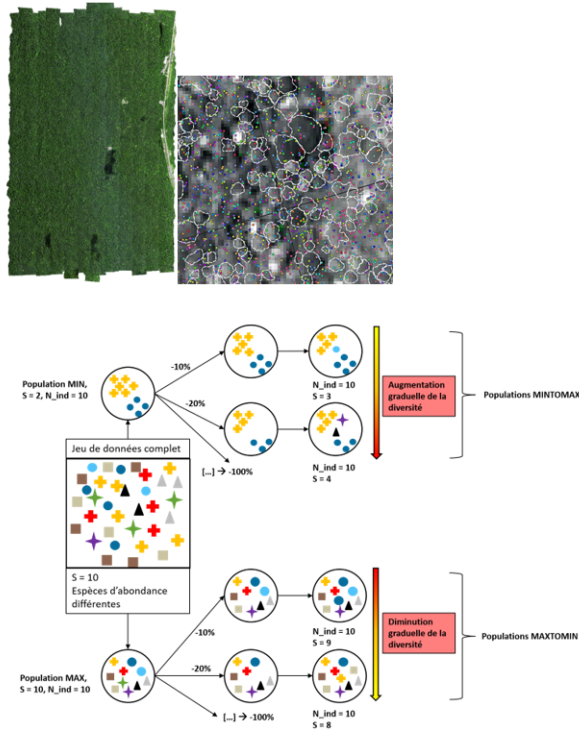


FIGURE 5 – Procedure to generate artificial populations of variable richness, equitability and diversity.

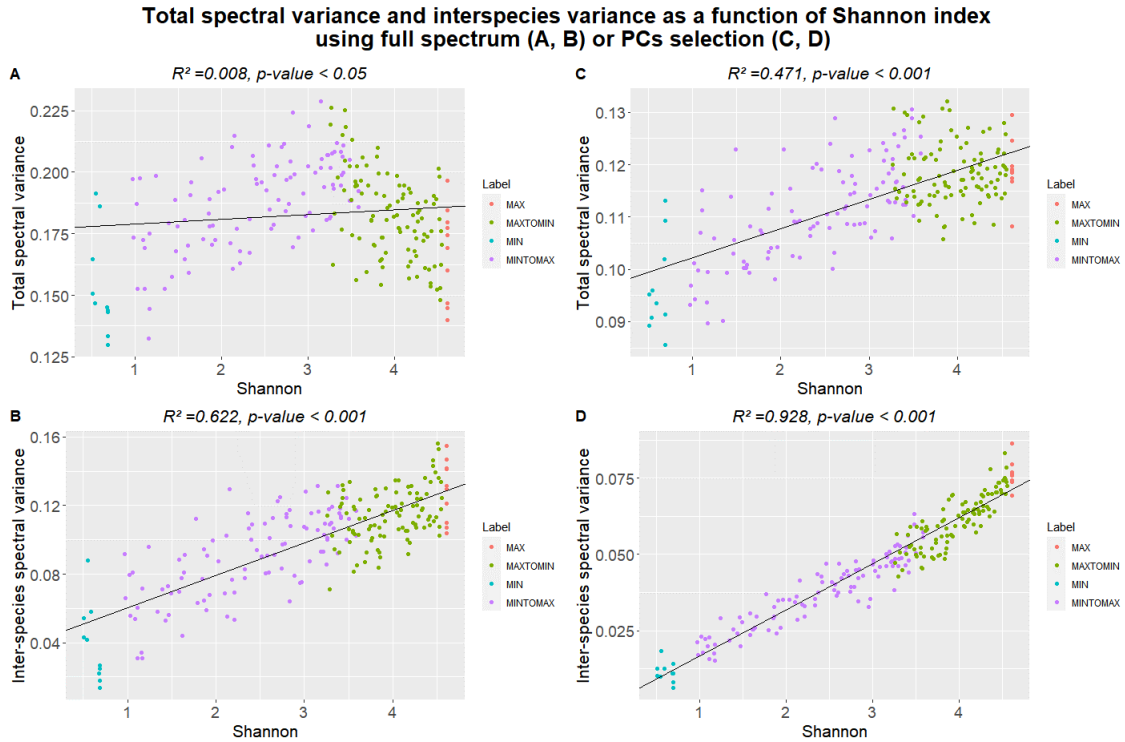


FIGURE 6 – Comparaison de la variance spectrale totale et de la variance inter-espèces en fonction de l'indice de Shannon. (A, B) sont les résultats obtenus avec l'ensemble des données spectrales. (C, D) sont les résultats obtenus avec les PCs sélectionnés

3 Architecture et variabilité interspécifique de trois espèces de *Baracoffea* : *Coffea boinensis*, *Coffea bissetiae* et *C. ambongensis* Davis & Rakotonasolo.

Author	Rickarlos BEZANDRY
Mail	richarlos@hotmail.fr
Supervisors	Sylvie SABATIER A., RANARJAONA H.L.T., Romain GUYOT, VAVITSARA M. Elodie.
Keywords	Caféiers sauvages xérophytiques, <i>Baracoffea</i> , Architecture, variabilité, Ankarafantsika, Antsanitia.

Le groupe des *Baracoffea* comprend 9 espèces endémiques à feuilles caduques qui sont exclusivement présentes dans les forêts sèches de la côte Ouest de Madagascar. Elles sont particulièrement bien adaptées aux conditions xérophytiques. La déforestation et les activités anthropiques ont provoqué dans l'île une forte fragmentation de la forêt et modifié considérablement les écosystèmes forestiers naturels. En conséquence, près de 75% des espèces malgaches, en particulier *Baracoffea*, sont classées sur la liste de l'IUCN comme vulnérables, menacées ou fortement menacées de disparition. Une meilleure connaissance de ces espèces est indispensable pour faciliter leur préservation. Pourtant, ces espèces sont trop peu étudiées en dehors de leur description botanique. L'objectif de cette étude est de mettre en évidence le mode de développement et les stratégies d'adaptation à la sécheresse de trois espèces de *Baracoffea* : *C. boinensis*, *C. bissetiae* et *C. ambongensis*. Sur le terrain, la méthode d'analyse architecturale de Edelin [6] et de Barthelemy [7], basée sur l'observation des critères morphologiques a été adoptée. Des mesures, comptages et pesages ont été aussi effectués au niveau des organes végétatifs et des graines de plusieurs individus par espèce afin d'identifier la variabilité inter-spécifique. En effet, l'unité architecturale de *Baracoffea* est composée de quatre catégories d'axe présentant une mode de croissance rythmique, ramification latérale et sexualité terminale portée par les rameaux courts. Des différences significatives sont observées entre ces 3 espèces aussi bien sur les différentes catégories d'axe que sur les graines. Au stade adulte, le tronc A1 de *C. boinensis*, *C. bissetiae* et *C. ambongensis* ont des longueurs¹, diamètres² et nombres³ d'entre-noeuds moyens respectivement de : $8.66 \pm 5.50\text{cm}$, $7.46 \pm 6.57\text{cm}$ et $6.55 \pm 6.33\text{cm}^1$ ($p < 0.001^{***}$) ; $1.20 \pm 0.80\text{cm}$, $1.45 \pm 0.80\text{cm}$ et $1.45 \pm 1.11\text{cm}^2$ ($p < 0.005^{**}$) ; 22 ± 3.96 , 48 ± 14.59 et 38 ± 7.57^3 ($p < 0.001^{***}$). Par ailleurs, les masses¹, les longueurs² et les largeurs³ moyennes des graines de ces trois espèces correspondent respectivement de : $0.29 \pm 0.09\text{g}$, $0.06 \pm 0.02\text{g}$ et $0.53 \pm 0.13\text{g}^1$ ($p < 0.001^{***}$) ; $14.32 \pm 0.11\text{mm}$, $6.33 \pm 0.46\text{mm}$ et $15.70 \pm 1.37\text{mm}^2$; $10.17 \pm 0.87\text{mm}$, $5.68 \pm 5.80\text{mm}$ et $11.35 \pm 1.19\text{mm}^3$ ($p < 0.001^{***}$). Les résultats obtenus comparés à l'architecture de référence du genre *Coffea* permettent de confirmer l'adaptation de *Baracoffea* par rapport au contexte climatique auquel elle a évolué par l'acquisition et modification spatio-temporelle de certains traits morphologiques.

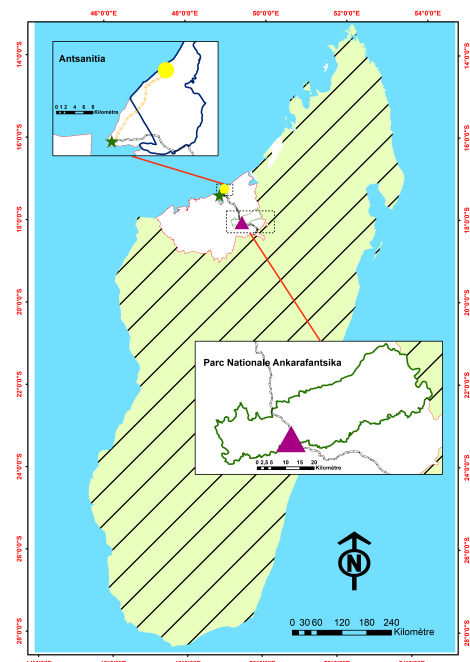


FIGURE 7 – Cartographie des sites d'étude.

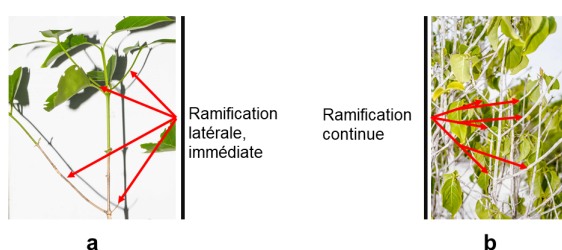


FIGURE 8 – Modes de ramification. **a** : ramification latérale et **b** : ramification continue.

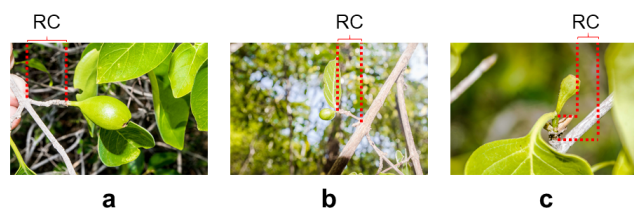


FIGURE 9 – Sexualité terminale portée par les rameaux-courts. **a** : sexualité de *C. boinensis*; **b** : sexualité de *C. bisetiae* et **c** : sexualité de *C. ambongensis*. **Légende** : RC : rameau-court.

Tableau 2-1 : Longueur moyenne des entrenœuds (en cm) en fonction de l'ordre de ramification des axes au stade de développement 4.

Stade 4	<i>C. boinensis</i>	<i>C. bisetiae</i>	<i>C. ambongensis</i>	Signification
A1	8,66 (±5,50) a	7,47 (±6,57) b	6,55 (±6,33) c	P<0,001***
A2	5,66 (±3,50) a	4,40 (±2,43) b	3,33 (±2,43) c	P<0,001***
A3	4,44 (±2,42) a	3,51 (±2) b	2,42 (±1,90) c	P<0,001***

Tableau 2-2 : Diamètre moyen des entrenœuds (en cm) en fonction de l'ordre de ramification des axes au stade de développement 4.

Stade 4	<i>C. boinensis</i>	<i>C. bisetiae</i>	<i>C. ambongensis</i>	Signification
A1	1,20 (±0,80) b	1,45 (0,80) a	1,45 (±1,11) ab	P<0,005**
A2	0,36 (±0,12) b	0,25 (±0,14) c	0,45 (±0,27) a	P<0,001***
A3	0,22 (±0,07) b	0,16 (±0,10) c	0,31 (±0,10) a	P<0,001***

Tableau 2-3 : Nombre moyen des entrenœuds en fonction de l'ordre de ramification au stade de développement 4.

Stade 4	<i>C. boinensis</i>	<i>C. bisetiae</i>	<i>C. ambongensis</i>	Si
A1	22 (±3,96) b	48 (±14,59) a	38 (±7,57) a	P.
A2	8,54 (±3,70) b	15,03 (±5,79) a	14,93 (±7,81) a	P.
A3	4,63 (±2,40) b	10,53 (±4,40) a	9,88 (±5,29) a	P.

Tableau 3 : Masse, longueur et largeur moyenne des graines

	Masse (g)	Longueur (mm)	Largeur (mm)
<i>C. boinensis</i>	0,29 (±0,09) b	14,32 (±0,66) b	10,17 (±0,87) b
<i>C. bisetiae</i>	0,06 (±0,02) c	06,33 (±0,46) c	05,68 (±5,80) c
<i>C. ambongensis</i>	0,53 (±0,13) a	15,70 (±0,37) a	11,35 (±1,19) a
Seuil de	P<0,001***	P<0,001***	P<0,001***
signification			
Classement	a > b > c		

4 Predicting tree species vulnerability to climate change in the tropical forest of French Guiana using joint species distribution models

Author	Jeanne CLEMENT
Mail	jeanne.clement@cirad.fr
Supervisors	Pierre COUTERON, UMR AMAP, Montpellier, France, Ghislain VIEILLEDENT, UMR AMAP, Montpellier, France
Keywords	Tropical ecology, Biodiversity, JSDB, Climate change, Functional traits and phylogeny, Bayesian hierarchical models, Monte Carlo Markov Chain, Gibbs sampling

Climate change risks having a strong impact on tropical forests through changes in species distribution and community composition. Species distribution models (SDMs) are commonly used in ecology to predict the ecological niche of a species and its vulnerability to climate change but they do not take into account interactions between species and very often consider only an environmental filter to predict the occurrence of species (abundance or probability of occurrence).

Joint Species Distribution Models (JSDMs), which have recently emerged in ecology, allow to take into account interactions between species to predict their occurrence. This approach is particularly interesting for rare species which can borrow information from other more abundant species. These models provide a conceptual framework for integrating phylogeny or functional traits to explain differences in occurrence between species [8]. JSDMs have known a rapid expansion in recent years with the development of several libraries to fit this type of model according to different statistical approaches : R packages `Hmsc` [9], `gjam` [10], `BayesComm` [11], `boral` [8] or `s-jSDM` [12]. However, these libraries may have some limitations, they do not all allow (i) the processing of large data-sets, (ii) extrapolation between observation sites to obtain predictive maps and (iii) the handling of presence only data (typical of herbarium data for example) or missing data.

This project relies on the development of the R package named `jSDM` (<https://ecology.ghislainv.fr/jSDM>) to overcome the limitations of existing libraries for fitting joint species distribution models . The `jSDM` package includes a Gibbs sampler with block sampling of some parameters, implemented in C++, it is optimized and allows the estimation of parameters for large datasets in a limited time. Additional functions are under development in order to (i) integrate phylogeny and functional traits as explanatory factors for differences in occurrence between species, (ii) to be able to spatially extrapolate occurrences between surveyed sites to obtain predictive maps [13] and (iii) to handle presence only data. Furthermore, using real datasets existing in the literature [12, 14] and virtual datasets, we will compare the predictive performance and computational time of the `jSDM` package with those of different existing libraries and statistical methods.

The main objectives of this thesis are : (i) to explain the differences in species vulnerability to climate change from a functional and phylogenetic point of view, (ii) to predict changes in species ranges and tree community composition under climate change and (iii) to identify biodiversity refuge areas in French Guiana using the `jSDM` package.

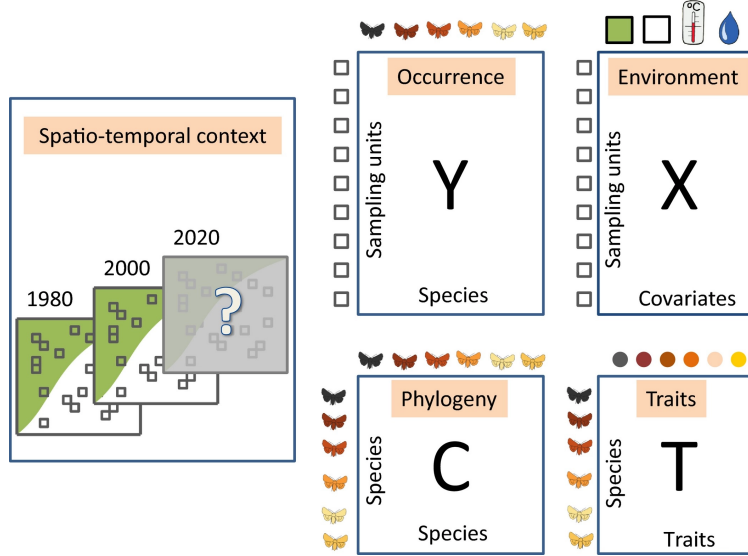


FIGURE 10 – Data typically used in community ecology to fit joint species distribution models (JSDMs) [9]. The occurrence data (denoted as the \mathbf{Y} matrix) includes the occurrences of the species recorded in a set of temporal and/or spatial sampling units. The environmental data (denoted as the \mathbf{X} matrix) consists of the environmental covariates measured over the sampling units. The traits data (denoted as the \mathbf{T} matrix) consists of a set of traits measured for the species present in the \mathbf{Y} matrix. To account for the phylogenetic dependencies among the species, we can include a fourth matrix consisting of the phylogenetic correlations among the species (denoted as the \mathbf{C} matrix). The spatiotemporal context includes location and time information about the samples.

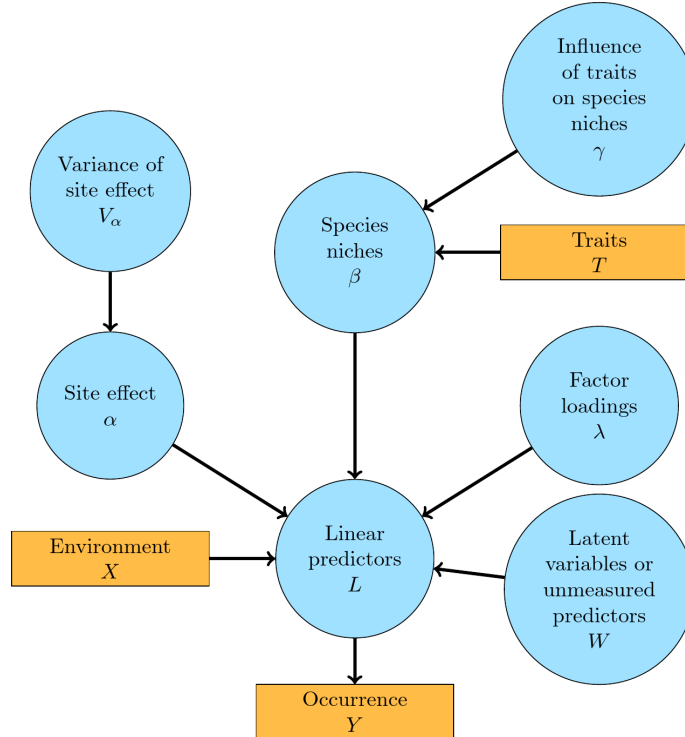


FIGURE 11 – A graphical summary of the jSDM bayesian framework. In this Directed Acyclic Graph (DAG), the orange boxes refer to data, the blue circles to parameters to be estimated, and the arrows to functional relationships described with the help of statistical distributions.

5 Impact des lianes sur la croissance des arbres dans une forêt du Nord Congo

Author	Carla DELLA SIGNORA
Mail	carla.della_signora@cirad.fr
Supervisors	Asli-Begum Kacamak, Maxime Réjou-Méchain
Keywords	Canopy, Growth, Remote sensing, Woody vines

5.1 Contexte du stage :

Les lianes sont des composantes essentielles des forêts tropicales. Elles représentent jusqu'à 20% de la diversité des plantes ligneuses et jusqu'à 4% de la densité des tiges (≥ 1 cm de DBH) en forêts néo-tropicales [15]. Ce sont des plantes grimpantes qui germent au sol et perdent leur capacité à se porter en grandissant, qui ont donc besoin d'un support extérieur physique pour s'élever jusqu'à la canopée. La majorité des lianes forme à terme une couche de feuilles recouvrant la couronne des arbres et rentrent donc en compétition directe pour la lumière et l'espace avec ces derniers [16, 17].

Les lianes ont souvent été étudiées pour leur impact négatif sur la dynamique forestière. Elles réduisent la diversité des arbres, leur croissance, le stockage du carbone et limitent la résilience des forêts [18, 19, 20]. Cependant les interactions entre lianes-arbres ont majoritairement été étudiées à travers des mesures au sol, comme la surface terrière des lianes, leur densité de tiges ou l'indice d'infestation de la couronne (COI) [21, 22]. Une récente étude a souligné que ces mesures classiques du sol ne reflètent pas correctement la couverture foliaire des lianes sur les couronnes des arbres [23], soulevant des questions sur les conclusions tirées de ces estimations pour étudier l'impact des lianes sur les arbres.

Ce projet de stage s'inscrit dans une étude visant à quantifier l'impact des lianes sur la croissance des arbres à travers des mesures drones, et à comparer ces résultats avec l'impact quantifié à travers des mesures classiques du sol.

5.2 Objectifs :

1. Relier les arbres mesurés au sol à ceux vu depuis le dessus de la canopée par données drones
2. Mesurer les lianes depuis le sol
3. Segmenter semi-automatiquement les couronnes d'arbres à partir de données Lidar et images drones RGB déjà acquises
4. Croiser les données de lianes (sol et drone) avec les données d'inventaire d'arbres pour quantifier l'impact des lianes sur la croissance des arbres.

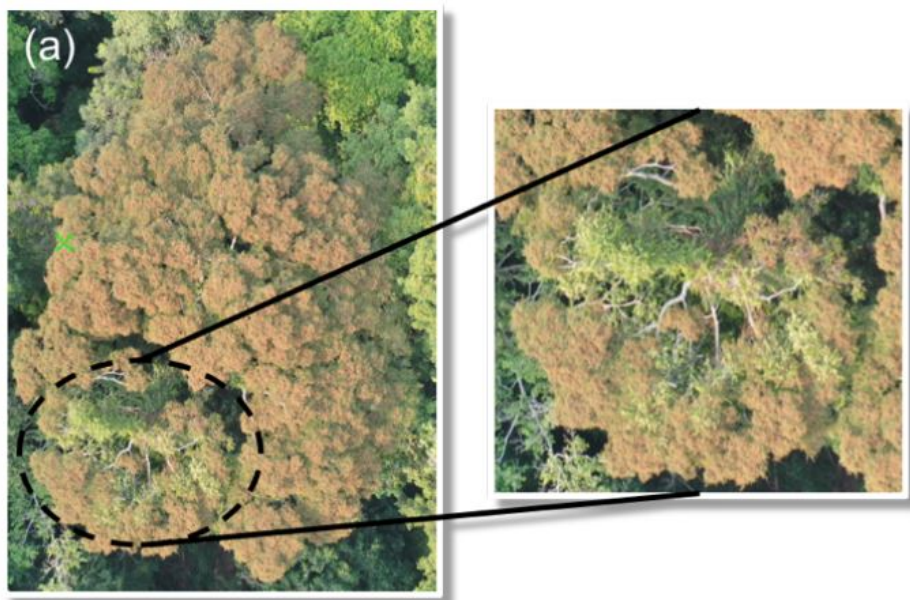


FIGURE 12 – Exemple d'identification d'une liane sur une couronne d'arbre et délimitation de la liane

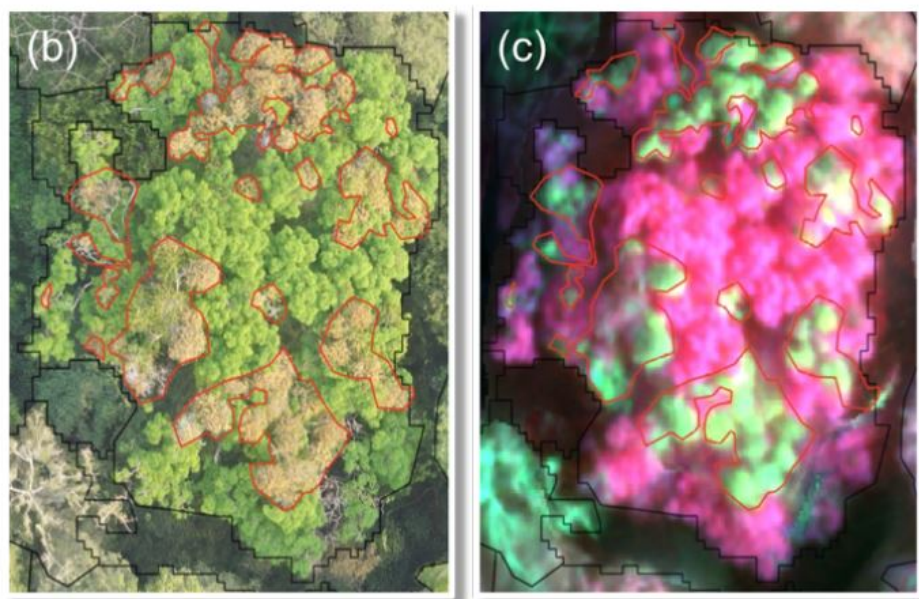


FIGURE 13 – Délimitation de lianes sur images RGB (b) et images multispectrales (c)

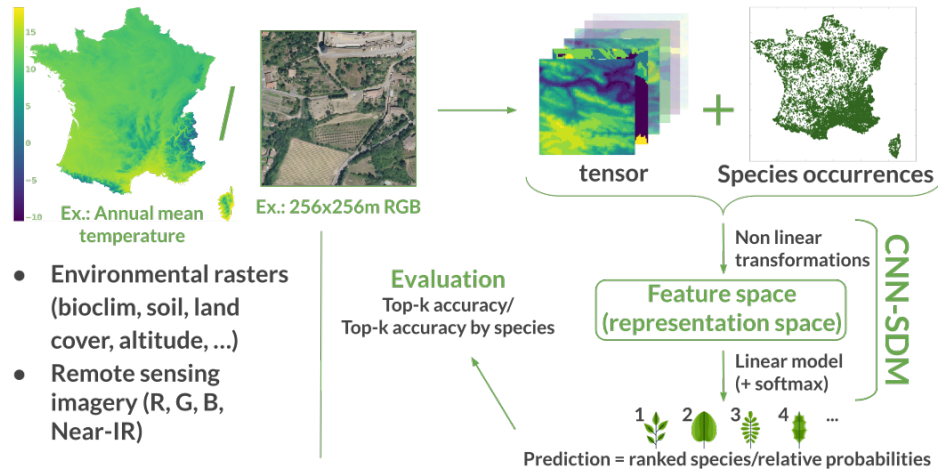
6 Interpretability of distribution models of plant species communities learned through deep learning - application to crop weeds in the context of agro-ecology

Author	Benjamin DENEU
Mail	benjamin.deneu@inria.fr
Supervisors	Alexis JOLY (Inria/LIRMM – Montpellier), François MUNOZ (Université Grenoble Alpes/LECA – Grenoble), Pierre BONNET (Cirad/AMAP – Montpellier), Maximilien SERVAJEAN (Université Paul Valéry/LIRMM - Montpellier)
Keywords	Species distribution modeling, Agro-ecology, Deep Neural Networks, Transfer learning, Interpretability, Interactions, Landscape, Agricultural Practice, Biodiversity, Crop Weeds

The modeling of interactions between biodiversity, landscape and agricultural practice is one of the major challenges of agro-ecology. Very recently, environmental species distribution models based on deep neural networks have begun to emerge. These first experiments showed that they could have a strong predictive power, potentially much better than the models used traditionally in ecology. One of their advantages is that they can learn an environmental representation space (named “features space”) common to a very large number of species so that the prediction performance can be stabilized from one species to another. This allowed particularly better performance than the state-of-the-art models on rare species benefiting from the simultaneous learning on frequent species. Another advantage of these models is that they can be learned on very high dimensional data without overfitting. This leads to the use of tensors instead of input vectors and the possibility to use aerial view or remote sensing data.

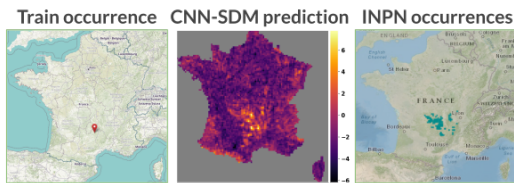
This thesis focuses on the interpretability of these models and their predictive power with a case study focused on crop weeds. The first interpretability studies focused on the contribution of the input data. This revealed that the use of tensors, especially on environmental variables, gives access to local structuring information of the environment, not present in a punctual vector, which explains in part the gain in performance compared to state-of-the-art models. The feature space analysis allows to quantify and visualize the information captured by the model. Using a dimension reduction method (t-SNE) we can reduce the feature space to 2 or 3 dimensions allowing different qualitative projections. In particular, the projection of the input data onto this reduced feature space, or the projection of the feature space into geographic space, highlights that the model captures both large-scale and fine-resolution information. Dimension reduction also allows to highlight correlations between the model training and complementary data representing certain ecological aspects, such as functional traits. In the case of the deep agri-environmental models targeted in the thesis, these studies will also integrate information from the landscape and agricultural practices. Their analysis will provide a better understanding of whether or not massive integrative approaches, based on a wide variety of input data, are needed, or whether they should focus on certain key factors.

Deep Species Distribution Models (CNN-SDM)

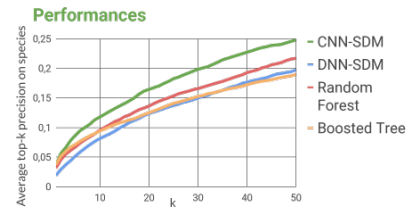


Benefits of CNN-SDM

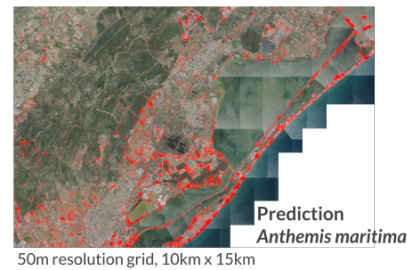
1. Better overall performances →



Ex: Prediction *Senecio caliciaster* Lam. (1 train occurrence)



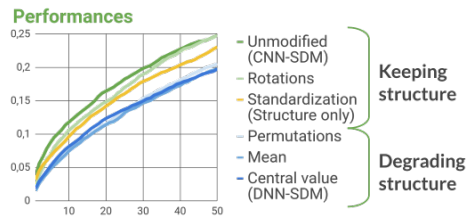
← 2. Rare species prediction



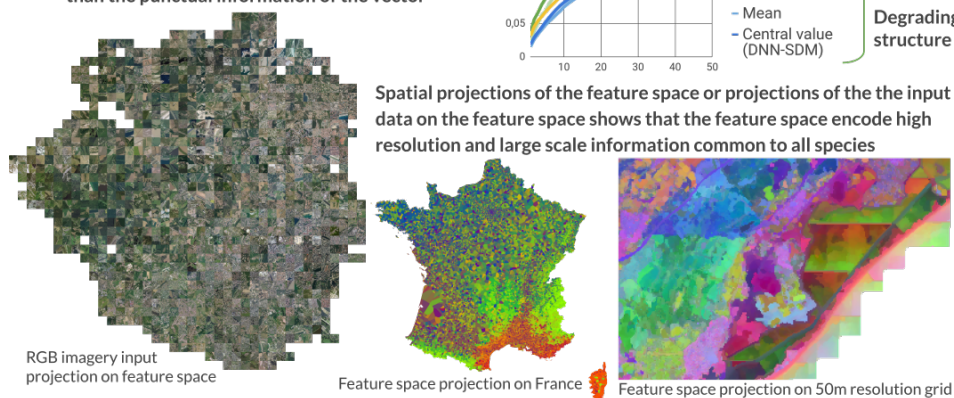
3. High resolution prediction →

Interpretability

Ablation studies shows that the spatial structure information in the tensors is richer than the punctual information of the vector



Spatial projections of the feature space or projections of the the input data on the feature space shows that the feature space encode high resolution and large scale information common to all species



7 A predictive approach to determining the joint conservation status of species

Author	Joaquim ESTOPINAN
Mail	joaquim.estopinan@inria.fr
Supervisors	Alexis JOLY, François MUNOZ, Pierre BONNET, Maximilien SERVAJEAN

The IUCN Red List is now the global reference for listing species at risk of extinction. The evaluation process of species conservation status has been unified in 5 synthetic criteria on population sizes, geographical distributions, threats and their dynamics. About 86% of mammals (5,792 out of 6,500) now have a conservation status assigned, compared to less than 8% of the 352,000 plant species estimated worldwide. There is therefore an urgent need to assess plants and guide conservation policies in the face of habitat destruction and climate change. The manual IUCN assessment process is time-consuming, so the help of automatic assessments is a promising solution. The scientific community is currently seizing on artificial intelligence tools to hopefully achieve robust extinction risk classification methods. However, many key problems deserve special attention before claiming to faithfully approximate the manual method. They mainly concern the availability and quality of the input data : how to capture threats on species, how to deal with presence-only data, with observation bias or very uneven species distributions ? Compensatory machine learning strategies can help to solve these hard problems : deep learning, transfer learning, multitasking etc. My work lies then at the intersection between Conservation and Computer science. To start with, we decided to base our work on the Orchid family which is fragile and a good indicator of ecosystems' health. An already filtered (taxonomically and geographically) occurrences set encompassing one million geolocated observations (14000 species) is being used. Around each of them, image-series from Sentinel-2 satellites were collected to create a dataset informing on species environmental preferences. First experiments feeding Species Distribution Models (SDMs) with these satellite image-series are highlighting the contribution of the temporal dimension. Other data sources will soon be exploited to grasp complementary information on species habitat : altitude, bioclimatic and soil variables, human footprint, but also longitude and latitude. The objective being to take into account as many aspects as possible informing species IUCN status.

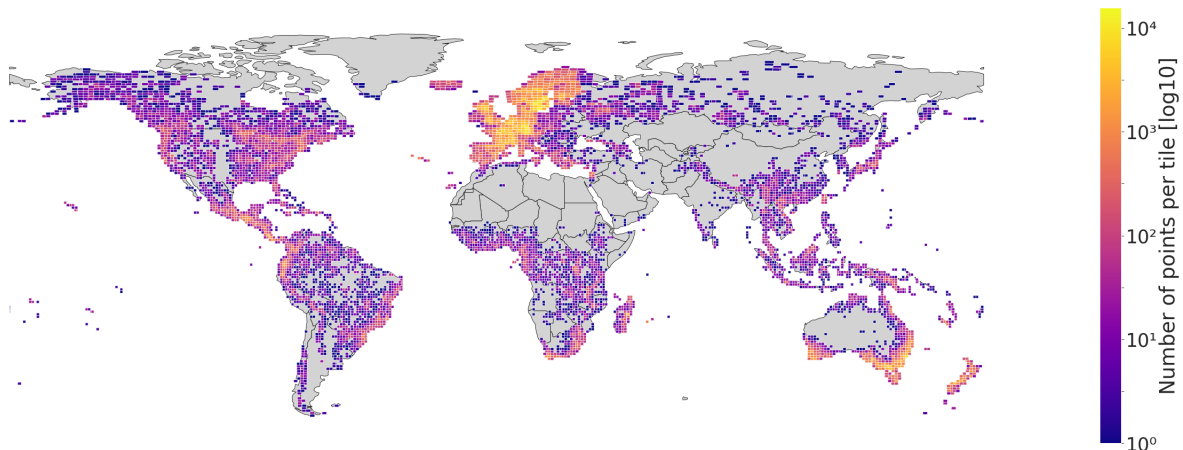


FIGURE 14 – Map of selected Sentinel-2 tiles coloured in function of the number of records contained (log10 scale).

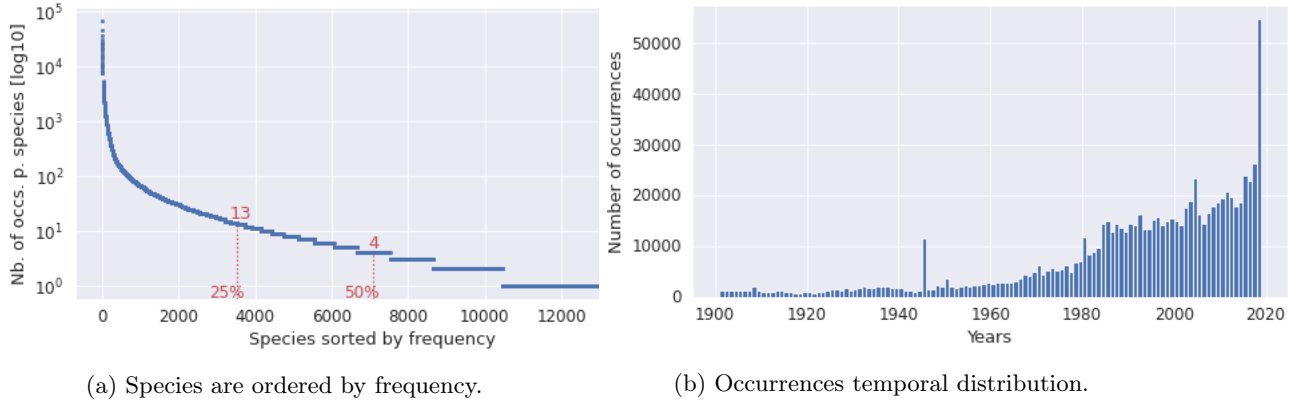


FIGURE 15 – Whole dataset occurrences distribution.

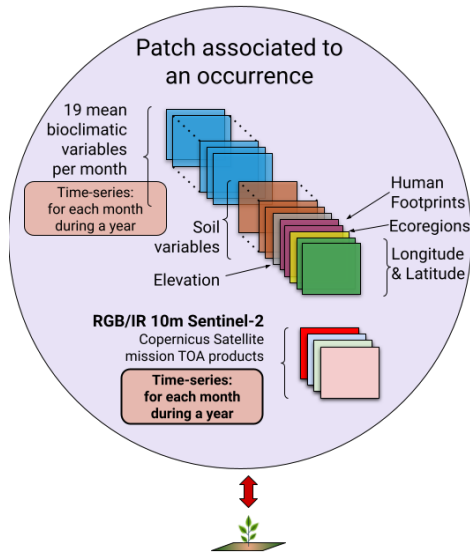


FIGURE 16 – Stacked patch data informing a species' occurrence on its environment.

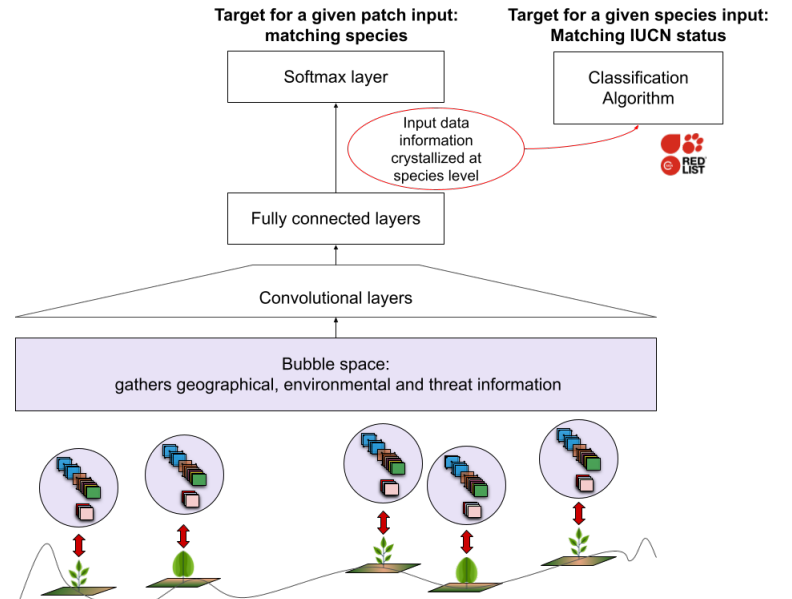


FIGURE 17 – Schematic models design, SDM and classifier.

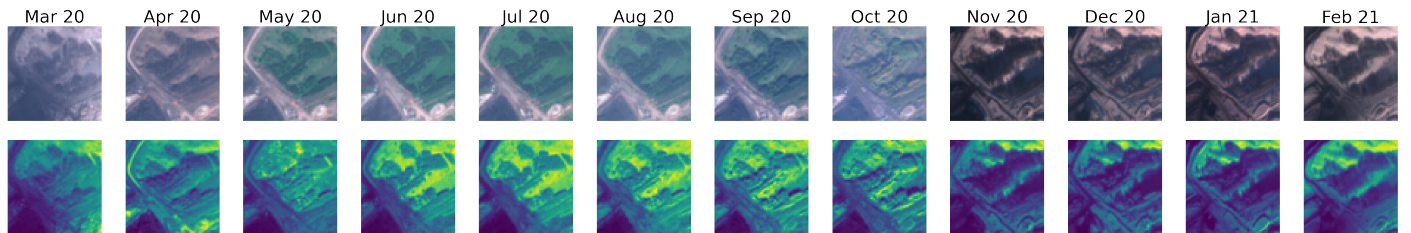


FIGURE 18 – Sentinel-2 RGB/IR image-series example.

8 What are the consequences of different types of intraspecific variability on community dynamics ?

Author	Camille GIRARD-TERCIEUX
Mail	camille.girard-tercieux@cirad.fr
Supervisors	Raphaël PELISSIER, Isabelle MARECHAUX, Ghislain VIEILLEDENT
Keywords	Intraspecific variability, community interactions, theoretical model, niche multidimensionality, species coexistence

Intraspecific variability (IV) is often viewed as a random noise around a species mean attribute (e.g. functional trait or performance proxy). However, another way to see it is the result of environmental variation to which plants respond. As environmental variations are often spatially and temporally structured, IV would then also be structured in space and time. These different types of IV could have different consequences on species interactions, and thus on community dynamics and species coexistence.

To examine these consequences, we built a theoretical setup using two consecutive theoretical models of community dynamics (Figure 19). The first model (Figure 19, step 1) does not include any random IV : all conspecific individuals respond in the same way, to three spatially structured environmental variables. The only way for a species to persist in a given environment is to have no superior competitor in the pool of the present species. The temporal series of species performance produced by this model are then used to infer IV (Figure 19, step 2), with a statistical model including only one of the three environmental variables as an explanatory variable, as would be the case in the statistical analysis of an ecological dataset if some environmental variables were unobserved. Consequently, this inferred (or observed) IV is mainly the result of the spatially structured variation of the environment in the two unobserved dimensions. This IV is then injected in the second model (Figure 19, step 3), where there is only one environmental axis (the same that was used to infer IV), as a stochastic noise around species parameters, i.e. a spatially unstructured IV. In this model, another way for a species to outcompete superior competitors in a given environment is to benefit from an inversion of the competitive hierarchies due to stochasticity. Outcomes of these two models, like species richness at equilibrium, spatial structure of the community (Figure 20) or stability of the dynamics across simulations, are then compared (Figure 19, step 4). This setup will enable us to discuss the level and stability of coexistence in both models. We hypothesise that in the second model where IV is treated as a noise, species coexistence will be less stable, demonstrating in a simple framework the importance of the nature of IV in community dynamics models.

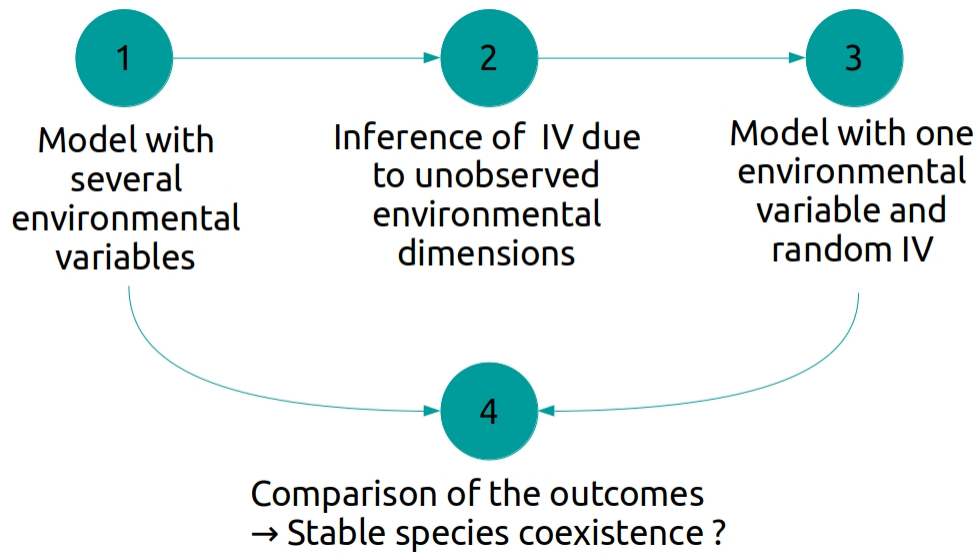


FIGURE 19 – General framework of the analysis.

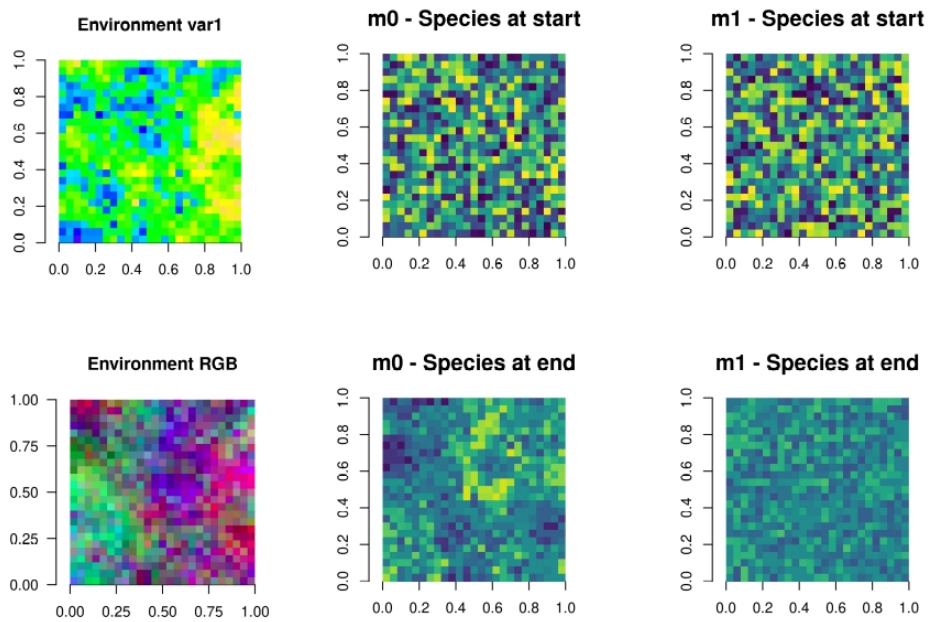


FIGURE 20 – Spatial structure of the environment (first dimension alone and three dimensions aggregated as RGB colors) and of the species community at the beginning and at the end of a simulation in both models.

9 Functional diversity of exploratory phases in climbing plants : a static, dynamic, and modelling approach of searcher shoots to enhance bio-inspired applications in soft robotics.

Author	Tom Hattermann
Mail	tom.hattermann@cirad.fr
Supervisors	Nicholas Rowe, UMR AMAP, CNRS, Montpellier, France Patrick Heuret, UMR AMAP, INRAe, Montpellier, France
Keywords	Climbing plants, Lianas ; Searcher shoot, Biomechanics, Plant anatomy and architecture, Biomimetic ; Soft-robotic

Climbing plants (i.e. scrambling shrubs, vines, lianas and nomadic plants) rely on physical supports to compete for light and disperse fruits. They exhibit remarkable vegetative capacity to colonize horizontally and vertically, different forest layers with proportionally much lower energy costs than self-supporting plants. High exploratory capacity result in complex life histories made difficult to predict their architectural development or their volume, dimensions and biomass from allometry equations and ground-based measurements. However, such aspects are currently controversial aspects for the calibration of dynamic global vegetation model and climate change prediction.

Improving our understanding of the spatial occupation of climbing plants is also of great interest for the development of new applications in the emerging sector of soft robotics. Climbing plants are inspiring models to develop kinematic systems based on additive processes able to explore unstructured environments. Their lightweight mechanical designs and high phenotypic plasticity are innovative considerations for the development of new applications in various fields as medicine, space exploration or environmental management.

In this context, I decided to focus my research work on the study of searcher shoots of climbing plants. Searcher shoots have specific phenotypical adaptations like the development of self-supporting stem and specialized organs responsible for locating and attaching supports (e.g. hooks, tendril and adhesive pads). To date, attachment mechanisms have been well studied in terms of diversity and functionality, but such aspects of searching mechanisms remain poorly documented. Moreover, we still ignore how various searcher shoot architecture is related with other climbing (i.e. spanning gaps, locating and attaching to support) and biological functions (i.e., photosynthesis, hydraulic conduction, mechanical support) and how these functions coordinate during different phases of shoot development. To document such aspects of the climbing habit of plants, my PhD project is structured according to the following three approaches :

1. investigate the structural and functional diversity of searcher shoots to characterize efficient self-supporting and support foraging architecture at the shoot level (static approach).
2. analyze searchers shoot movement using time-lapses to characterize growth behaviors and mechanical architecture that maximize volume exploration (dynamic approach).
3. collaborate with the H2020 GrowBot project consortium to mathematically formalize these biological processes and develop innovative biomimetic applications in soft robotic (modeling approach).

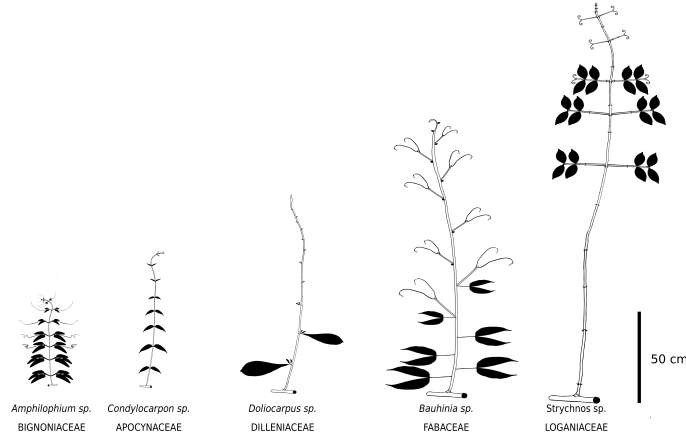


FIGURE 21 – Architectural diversity of searcher shoots with tropical examples from French Guiana : from the short gap-spanning searcher shoot of *Amphilophium* sp. to the long gap-spanning one of *Strychnos* sp..

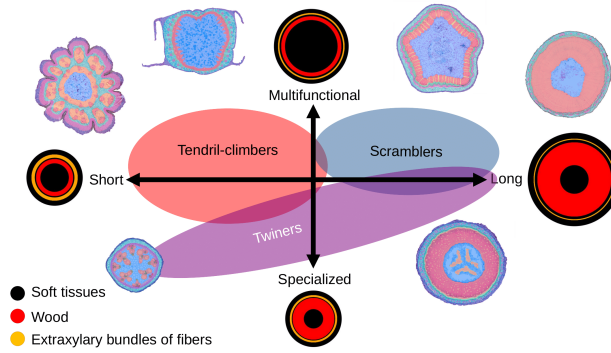


FIGURE 22 – Scheme of the functional diversity of searcher shoot along and around the gap-spanning axis of variation. Three main functional groups of searcher shoot were defined according to their mechanical architecture and climbing habit. Each group includes different degree of specialization toward support foraging functions.

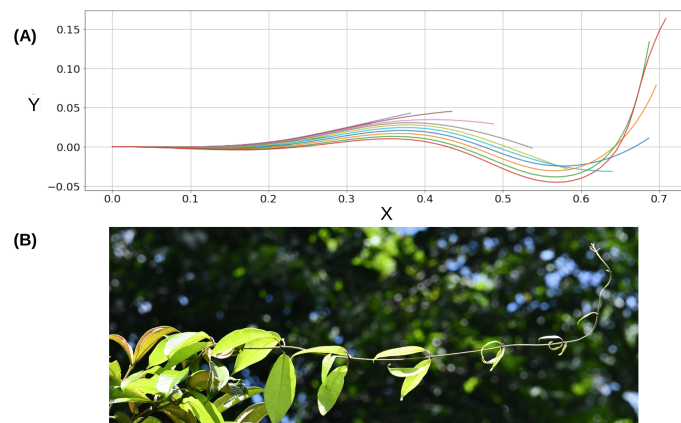


FIGURE 23 – Quantitative simulation of the self-supporting course of *Condyllocarpon guianense* (A) based on static description of the searcher shoot just before critical buckling (B). Simulation includes real measurements (bending properties, morphometry and spatial positioning proxies) and estimated parameters (growth rates, graviceptive and proprioceptive parameters).

10 Vegetation alters how soil properties and climate influence microbial activity and functional diversity in rhizosphere and bulk soil along an elevation gradient

Author	Hernández-Cáceres Daniel
Mail	digiocarina@hotmail.com
Supervisors	Alexia Stokes UMR AMAP, Montpellier, France. Guillermo Angeles Instituto de Ecología, Xalapa, Mexico
Keywords	elevational gradient, alpine, catabolic diversity, root traits

Microbial communities strongly influence ecological processes across space and time. However, the influence of abiotic and biotic factors on microbial functioning in montane soil environment is still poorly understood. We ask if microbial activity and functional diversity can be influenced by plant species identity and diversity and associated root system morphological and chemical traits, that also influence soil properties. We investigated microbial global catabolic activity (i.e. microbial activity) and catabolic diversity (i.e. functional diversity) in bulk and rhizospheric soil beneath three plant species (*Vaccinium myrtillus*, *Juniperus communis* and *Picea abies*), that shape local plant communities. To do this, we measured soil physical and chemical properties, climate variables and plant diversity along an elevational gradient (1400 - 2400 m a.s.l.) in the French Alps. Morphological and chemical traits of roots in bulk soil ('community' level traits, where several plant species were pooled together) and of individual plants ('species' level, where roots of single species were excavated) were measured. Results showed that at lower elevations, global catabolic activity in the rhizosphere was greater than in bulk soil, but converged in the nutrient-poor, colder soils found at higher elevations, although changes in catabolic diversity were negligible. Variations in soil physical and chemical properties were the main drivers of global catabolic activity, especially texture, cation exchange capacity, carbon and nitrogen content and pH, but their effects on catabolic diversity were minimal. Climatic influences on catabolic activity were more evident in soil from the rhizosphere compared to bulk soil, but this response was mediated by plant species. Plant root traits at the community level in bulk soil had less effect on global catabolic activity than abiotic factors, with thicker roots, high root lignin content and low cellulose content stimulating microbial activity, but not altering catabolic diversity. At the species level, more dense root tissue decreased global catabolic activity, reflecting changes in chemical composition. Our results show that climate and the soil physical and chemical properties are the main drivers of microbial activity and functioning, but that vegetation refines these relationships, probably through root exudation, root chemical composition and changes in litter production affecting soil carbon.

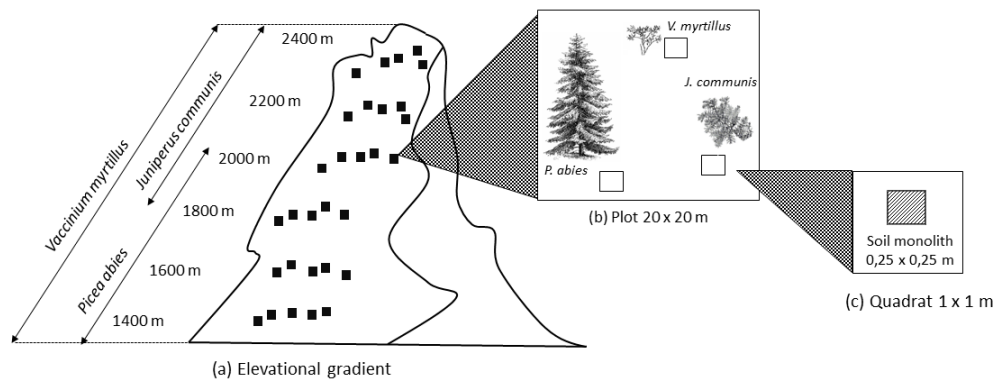


FIGURE 24 – Sampling design along the elevational gradient. (a) Six elevational bands, situated at 200 m from each other, were located along the gradient, ranging from 1400 m to 2400 m. Five plots (20 m x 20 m) containing two or three selected structuring plant species were located at each altitude. (b) At the canopy limit of the structuring plant species, a 1 m x 1 m botanical survey was performed. (c) In the center of this quadrat, a soil monolith (0.25 m x 0.25 m x 0.15 m) was extracted

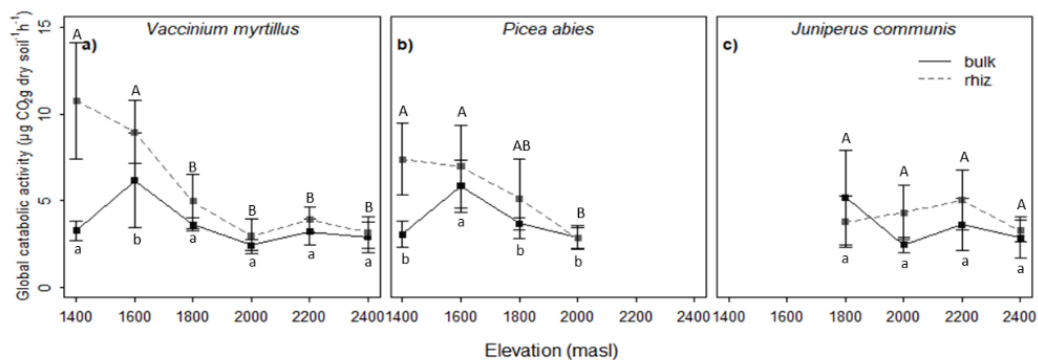


FIGURE 25 – Global catabolic activity of bulk soil (solid line) and rhizospheric soil (dotted line) beneath a) *Vaccinium myrtillus*, b) *Picea abies* and c) *Juniperus communis*. Data are means \pm standard deviation. Significant differences ($p < 0.05$) assessed by Tukey's HSD test are shown in lowercase (bulk soil) and uppercase (rhizospheric soil) letters.

11 Tracking tree mortality rate in a tropical moist forest using multi-temporal LiDAR

Author	Claudia Milena HUERTAS GARCIA
Mail	clauhuertas@gmail.com
Supervisors	Grégoire Vincent, UMR AMAP, Montpellier, France Raphaël Pélissier, UMR AMAP, Montpellier, France
Keywords	Mortality, Gap fraction, basal area loss, stem loss, canopy height loss, LiDAR, tropical forest

Measuring tree mortality rates is crucial to reducing uncertainties in the contribution of tropical forests to the carbon budget. Several studies have shown an increase in mortality in tropical forests in the last decades. However, we remain uncertain about the overall behavior because most studies are based on restricted areas or networks of plots. Hence, technological developments such as LiDAR (Laser Imaging Detection and Ranging) that promote the understanding of abiotic factors at local scales are critical, allowing us to identify specific spatial patterns in line with vulnerable areas, as identifying areas with more significant dynamics over time. This study aims to evaluate the potential of repeated airborne LiDAR scanning ALS (Airborne Laser Scanning) to map forest structure over large areas with high accuracy to detect landscape-level patterns of mortality. We combined surveys over 100 ha of permanent plots in a wide range of undisturbed and selectively logged dense forest structures and dynamics in French Guiana, sampled (> 1 ha) and compared them with gap fraction dynamics from canopy height models derived from three (2009-2015-2019) ALS datasets. In this study, we have demonstrated that multitemporal LIDAR (using gap fraction indicator) can produce reliable estimates of relative basal area loss ($R^2=0.74$) and mortality rates in natural forests and the ability to detect patterns related to local topography and their association with soil wetness (Figure 26) and canopy height (Figure 27). This study contributes to our comprehension of spatial and temporal patterns of mortality at the landscape scale, identifying limitations and generating recommendations for extrapolating this information to larger areas, supporting the accurate measurement of the carbon budget, as well as guiding policy and conservation actions in areas vulnerable to or at risk from climate change.

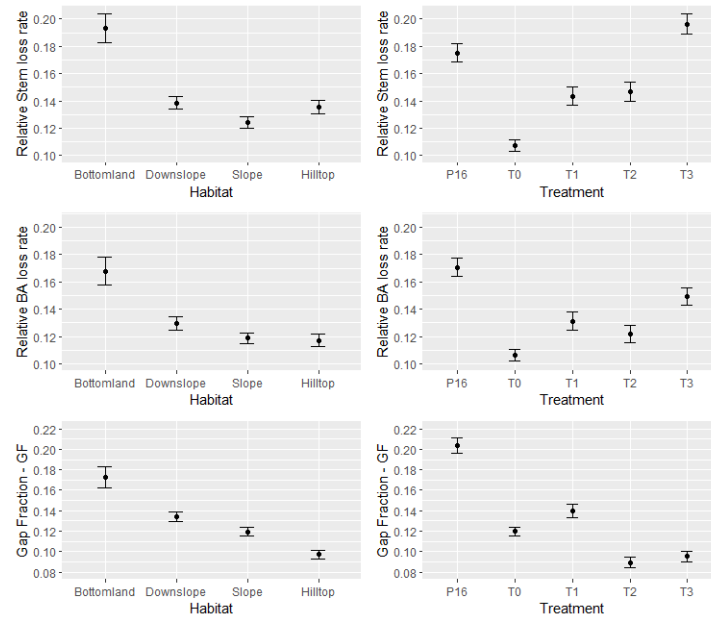


FIGURE 26 – The plot of the effects (Habitat, past disturbance level) on basal area loss, stem loss rate and gaps fraction over ten years in 2009-2019 (75 125x125 m subplots). Error bars represent 95 Percent Confidence Limits.

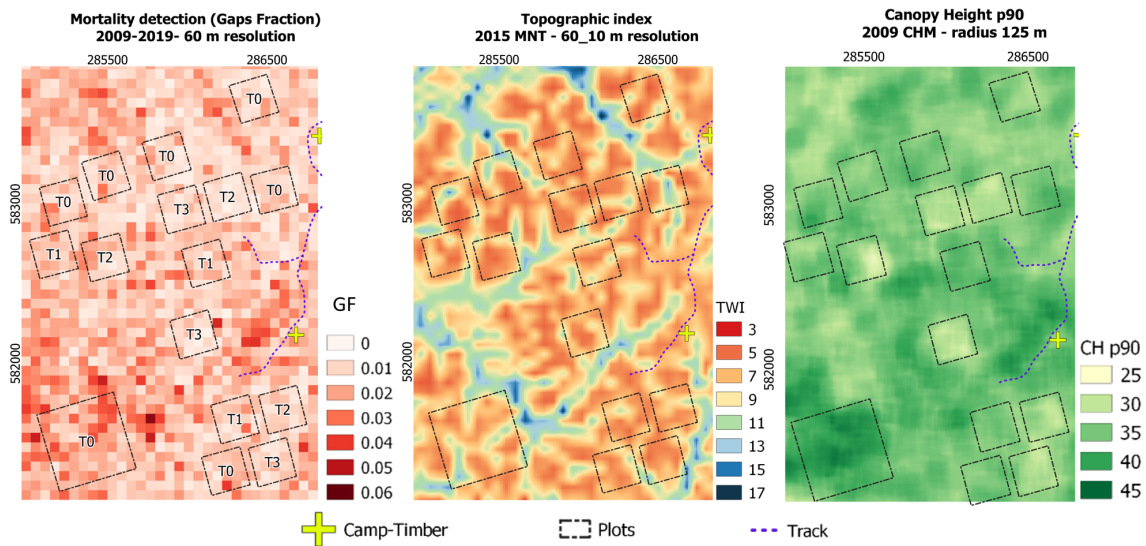


FIGURE 27 – Annualized gap fraction (GF) per pixel of 60 m b/ TWI (focal radius of 60, interpolated at 10 m) and height of the 90th percentile of the Canopy (CH) in a 125 m radius

12 Ecological strategies of African lianas in stable and disturbed environments : Bio inspiring models for soft robotics

Author	Asli Begum KACAMAK
Mail	asli-begum.kacamak@cirad.fr
Supervisors	Nick ROWE (AMAP, Montpellier), Vivien ROSSI (Forêts et Sociétés, Cameroun), Maxime REJOU-MECHAIN (AMAP, Montpellier), Sylvie GOURLET-FLEURY (Forêts et Sociétés, Montpellier)
Funding	GrowBot Project (CNRS), CIRAD
Keywords	Tropical ecology ; Lianas ; Forest dynamics ; Functional traits ; Biomimetic ; Soft-robotic

Lianas are essential components of tropical forests. They may represent up to 20% of woody plant diversity and 40% of stem density in Neotropical forests. They are in direct competition with trees for below-ground resources and mostly for light. They are mostly studied for their negative impact on forest dynamics. The ability to accurately estimate and monitor liana infestation is crucial to quantify their effects on forest functions, and understand the present and future dynamics of tropical forests. Lianas possess a wide range of strategies for climbing and colonizing trees, allowing them to adapt to different and unpredictable environments. This diversity is translated into wide-ranging structural and functional traits between species. They have mainly been considered as a single homogenous group in most studies on liana-tree interactions, whether about their impact on tree dynamics or a comparison with tree functional traits. However, a recent study has shown that liana trait variations are comparable in magnitude to tropical tree trait variations, within and across studies. Understanding lianas different growth strategies will help us to better understand liana-tree interactions and their distribution through space and time. This diversity of structural and functional traits is interesting not only to understand the distribution of species according to forest structure but also for the development of new innovative structures for new technologies, particularly in robotics. Therefore, this thesis has two main objectives. First, to understand the influence of liana communities on the natural and post-disturbance dynamics of tree stands and its consequences for silvicultural management. And second, to generate knowledge on the structural and functional characteristics of lianas in order to better understand species distribution and relationship with forest structure and to feed the development of a new type of soft robotics technologies.

Preliminary results :

- To accurately estimate liana infestation and their impact over trees, we looked at the relationship between ground liana measures and the photosynthetic liana leaves coverage over tree crowns measured by drones (delineated manually over RGB and Multispectral images [Figure 28]. We found that liana infestation was driven positively by liana basal area and negatively by tree height. The best model predicting liana leaves coverage over tree crowns was liana basal area [Figure 29a]. We also found a negative correlation between liana wood density and the residuals of the previous model [Figure 29b], indicating that lianas with lower wood densities tend to invest more into large photosynthetic surfaces over the canopy.
- We looked more closely into the different growth strategies of lianas through leaf and stem functional traits (LA, SLA, leaf thickness, cambial variants, wood density...). Preliminary results indicate 3 different cambial variant categories within liana species [Figure 30], with supposedly different resistance to disturbance properties, that we will test in the upcoming months and field missions.

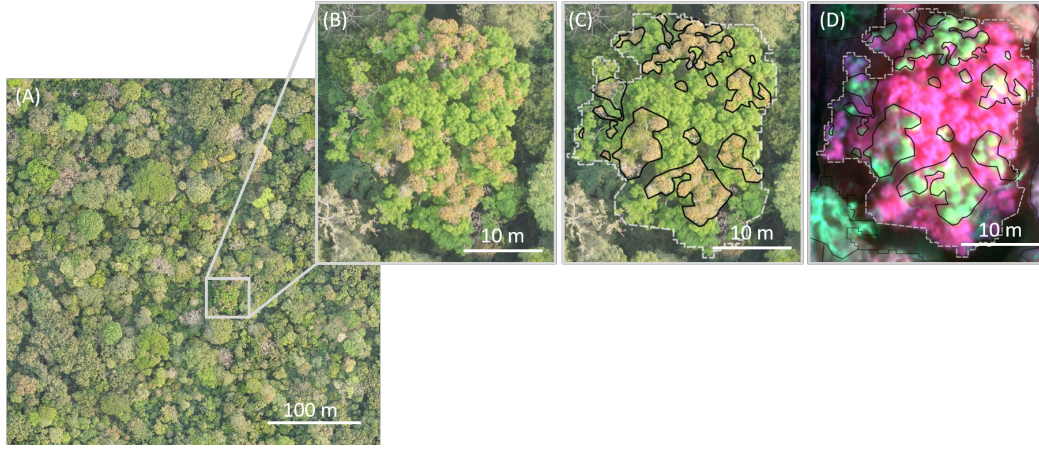
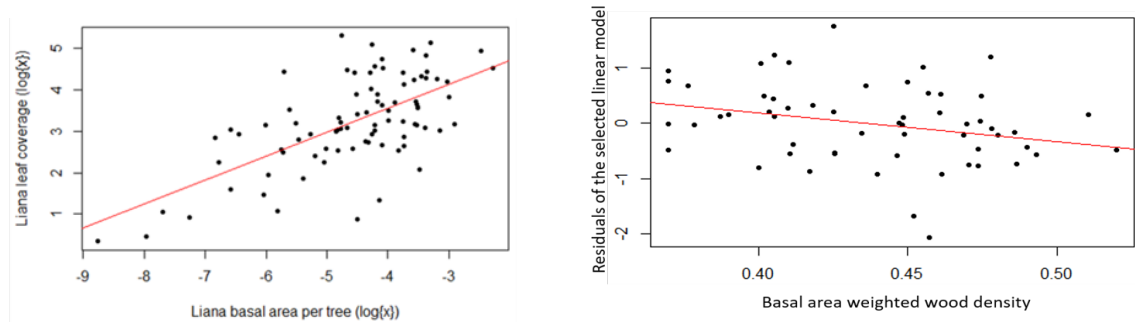


FIGURE 28 – Example of the manual delineation of liana leaves using RGB and multispectral data. (A) RGB mosaic of one of the two 9-ha plots. A liana-infested tree crown is illustrated before (B) and after (C-D) the manual delineation of lianas (in black lines) and the LiDAR segmentation of the tree crown with the AMS3D approach (in white dotted lines) on RGB (C) and multispectral (D) images.



(a) Relationship between total liana basal area measured from the ground and leaf coverage estimated from drone data for 86 tree crowns. (b) 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.

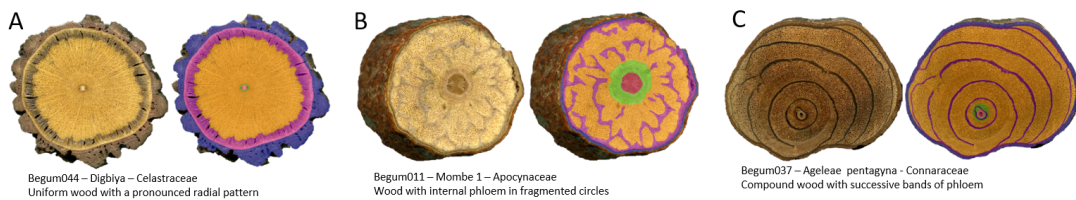


FIGURE 30 – Scans representing the different cambial variants within liana species. (A) Uniform wood, (B) Wood with internal phloem and (C) Compound wood. In pink the pit, green juvenile wood, yellow adult wood, purple phloem and blue the bark.

13 Environmental changes and structure, acquisition, and transmission of plant microbiota.

Author	LAFONT RAPNOUIL Tristan
Mail	tristan.lafontrapnouil@gmail.com
Supervisors	LEROY Céline
Funding	CEBA
Keywords	Microbiota, Plants, Metabarcoding, Environment, Community ecology, Tank Bromeliad, French Guyana

My PhD project aims to investigate the effects of abiotic factors (e.g., nutrient and water availability) on plant microbiota structure, acquisition, and transmission. I mainly focus on bacterial and fungal endophytes (living within plant tissues) associated with tank-bromeliads (Bromeliaceae) in French Guyana.

Over the last decade, great work has been made to describe the diversity and effects of the plant microbiota (epi- and endophytes) on plant growth, water and nutrient acquisition, stress resistance and protection against pathogen, insects, and herbivores. The association between a host and its microbiota, an entity known as the holobiont, has been proposed to be a new evolutionary unit. A key ecological and evolutionary aspects of the holobiont concept is its (in-)stability through time and hosts generations. The dynamic of the microbiota might represent a huge asset for plants facing changing environments but, on the other hand, holobiont stability might allow more complex and long-term cross generations interactions, leading potentially to coevolution of the partners. This balance between plant holobionts plasticity, stability and their drivers has potentially strong eco-evolutionary implications but is still poorly understood.

The plant holobiont appears to be the result of complex and dynamic interactions and feedback loop between its constituents and with their environment. My PhD project aims to explore the response of this plant holobiont (both microbial and plant levels) to environmental perturbations in the context of global change. I focus on the effects of environmental factors on microbiota composition, acquisition, transmission, and host performances via field and greenhouse experiments with tank-bromeliads in French Guyana.

The field experiments will essentially consist in (i) crossing rainfall amounts (4 levels representing climate scenarios) with habitat type (two levels, anthropogenic open vs pristine closed forest), and (ii) reciprocal transplantations of bromeliads between habitats under fixed drought conditions. In each habitat, we will use rainshelters placed over individual bromeliads (transparent plastic tarpaulin) to emulate dry periods representing the different rainfall scenarios. We will consider the response of the plants (ecophysiology) and its fungal and bacterial partners (metabarcoding ITS and 16s).

The greenhouses experiments aim to (i) obtain generation N+1 seeds from plants growing along a gradient of nutrient-availability and water-supply and, (ii) disentangle the environmental and maternal effects on offsprings microbiota and phenotype. Morphological, hydraulic and photosynthesis associated traits were measured on flowering mother plants. Leaves, roots, stem, flower, fruits, and seed tissues were sampled for each plant to conduct fungal and bacterial metabarcoding analysis. Extra seeds were sowed in a full factorial design to disentangle environmental and maternal effects on seedlings growth, performances, and microbiota. Besides these experiments on microbiota transmission, I track the effects of the same environmental factors (watering and soil richness) on seedlings microbiota in a 10 steps chronosequence from the seeds to six-months old plants. The aim is to disentangle the effects of environment and plant ontogeny on microbiota composition. Indeed, the balance between these two factors and the evolution of the inherited (starting point) towards the transmitted (ending point) communities are key to grasp the long term eco-evolutionary consequences of the host-microbiota interactions in plants.

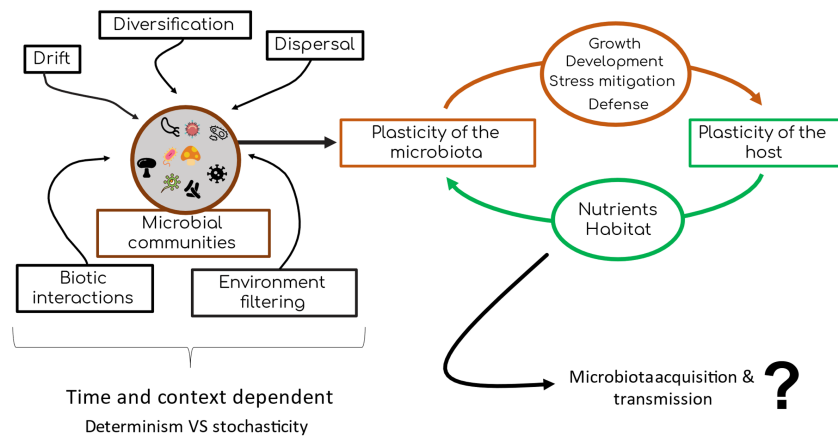


FIGURE 31 – Context of the subject

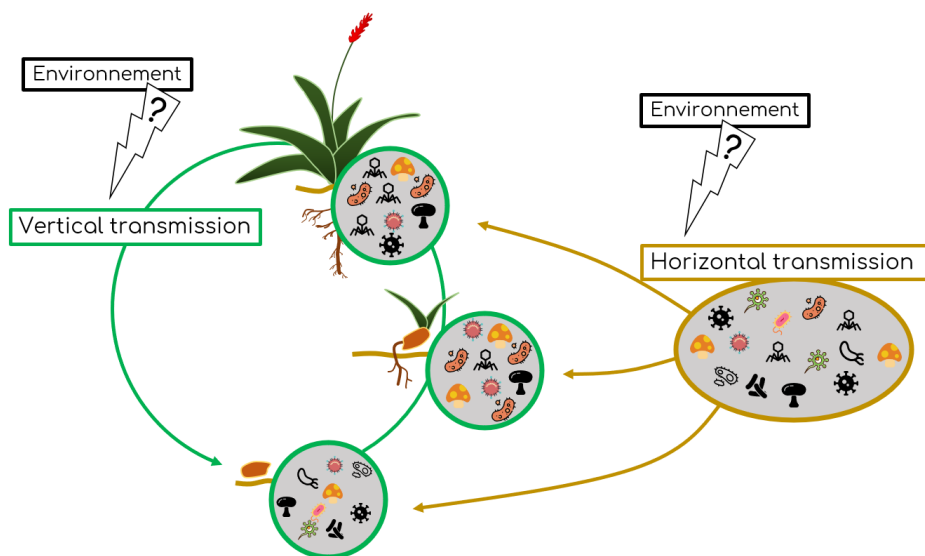


FIGURE 32 – Questions of the subject



FIGURE 33 – Setup

14 Augmented reality to facilitate agroforestry system design

Author	Laëtitia LEMIERE
Mail	laetitia.lemiere@inrae.fr
Supervisors	Marie GOSME, UMR ABSYS - INRAE Marc JAEGER, UMR AMAP - CIRAD, Gérard SUBSOL, équipe ICAR - LIRMM
Keywords	Augmented reality, Agroforestry, Visualization, Participative modeling tools

The design of an agroforestry system is a difficult task, which generally mobilizes different stakeholders in dedicated workshops. Indeed, an agroforestry system is a complex system where trees, crops and sometimes animals are associated [24]. These systems have many advantages, but their performance depends on the spatial organization of the area. Moreover, system performance is no longer considered only in terms of their production, but also in terms of the set of ecosystem services they provide, which can be classified into 4 categories [25] :

- Production : Product obtained from the ecosystem (Food, Fiber...).
- Regulation : Benefits obtained by regulating ecosystem processes (Climate regulation, Pollination...)
- Culture : Non-material benefits obtained from ecosystems (Aesthetics, cultural heritage...)
- Support : Services necessary for the production of all other ecosystem services (soil formation, nutrient cycling...)

To facilitate the design of agroforestry systems, we propose to develop tools to improve the representation of the system and its ecosystem services. Augmented reality is a good solution because it superimposes virtual elements on real elements. In this way, we can obtain an immersive visualization with an important interactivity. This technology has been known by the general public thanks to the Pokemon Go game, but it has since been used in many professional applications, in architecture, design, street navigation, advertising, education....

Estimating the (potential) provision of ecosystem services is essential when spatially designing agroforestry systems, to assess whether or not the designed system produces the ecosystem services desired by farmers. Spatial design consists of determining the elements (tree, crop, hedge, strip of understory vegetation...) of the system and their relative structural organization. They form patterns (Figure 34). A pattern is associated with a set of ecosystem services. The identification of this pattern is the first step to simulate the provision of ecosystem services and I am currently working on the identification and formalization of the patterns present in the newly designed systems. The next step will be to compute the relevant ecosystem services produced by the models, and finally to visualize them with augmented reality (Figure 35) directly on the physical representation of the system being designed, so as to allow maximum interactivity during the design workshops.

For some services such as aesthetics, it is complicated to imagine the visual impact of trees in the landscape. For this, we propose a second tool based on augmented reality : a projection of the future plot can be made in situ and correctly positioned with the GPS coordinates of the observer.

In conclusion, my thesis aims at facilitating the design of agroforestry systems by detecting patterns during the design phase and by modeling them to be able to calculate their production of ecosystem services and to visualize them. I am developing augmented reality prototypes that I will test during participatory design workshops.

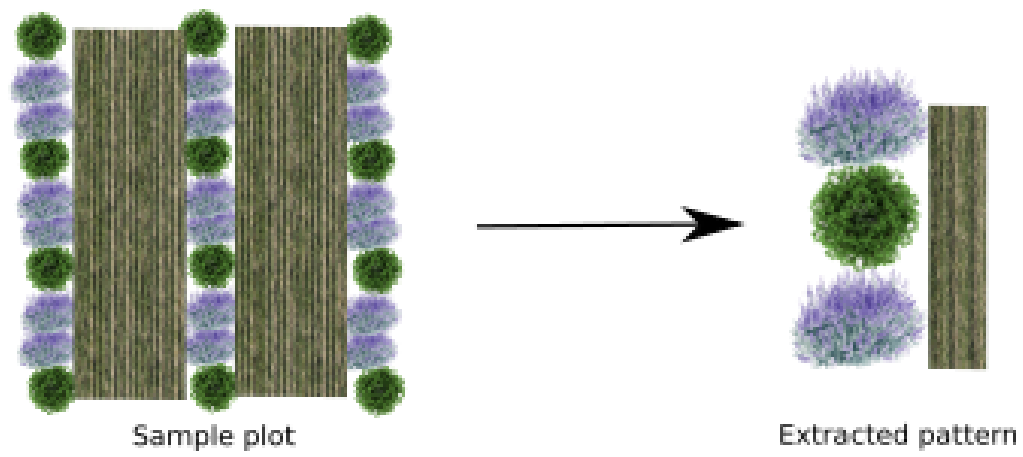


FIGURE 34 – pattern extraction from a crop

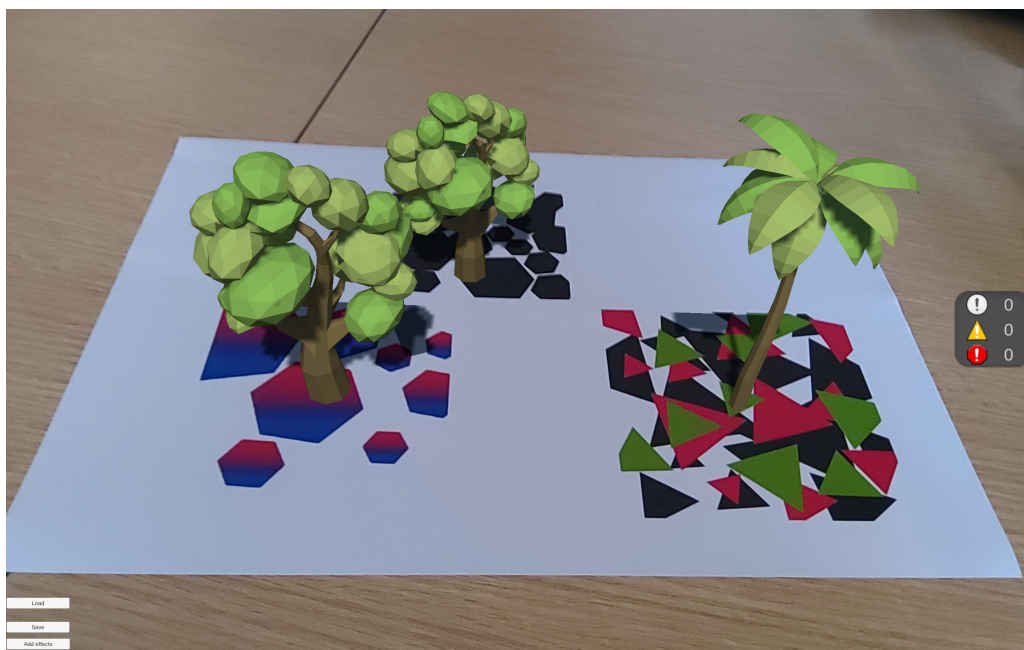


FIGURE 35 – Trees vizualization with augmented reality

15 Taxonomic ambiguities on *Silene* section *Silene* (*Caryophyllaceae*). : The case of *Silene nocturna* group

Author	Melilia MESBAH
Mail	melilia.mesbah@gmail.com
Supervisors	Mohamed SAHNOUNE (UAM Bejaia, Algeria), Errol VELA (INRAE, UMR AMAP, Montpellier, France), Bengt OXELMAN (GGBC, GU Gothenburg, Sweden)
Keywords	<i>Silene nocturna</i> , Genomic sequencing, Morphometry, application of the Linnaeus names.

Insights from molecular phylogenetics have significantly changed the taxonomy of the genus *Silene* by far the most diverse in the family of *Caryophyllaceae*, with approximately 870 currently accepted taxonomic species. An overview of a recent outcomes revising the infra-generic classification of the North African taxa with phylogenetic relationships is given, and some outstanding problems are highlighted to determine the right application of the Linnaeus names *Silene nocturna* L., *S. mutabilis* L. and *Cucubalus reflexus* L.

To improve the phylogenetic relationships and evolution within this group, a representative sampling including 84 populations from the Mediterranean were carried out Ongoing work based on biometrical analysis and genomic sequencing have been initiated to Determine how the morphological traits evolve between and within species is key to understanding patterns of speciation and resolve the taxonomic diversification withing the taxa belonging the *Silene nocturna* group.



(a) *Silene cirtensis*.



(b) *S. nocturna* clade 1.



(c) *S. nocturna* clade 2

FIGURE 36 – Pictures of some species belonging to *Silene nocturna* group :

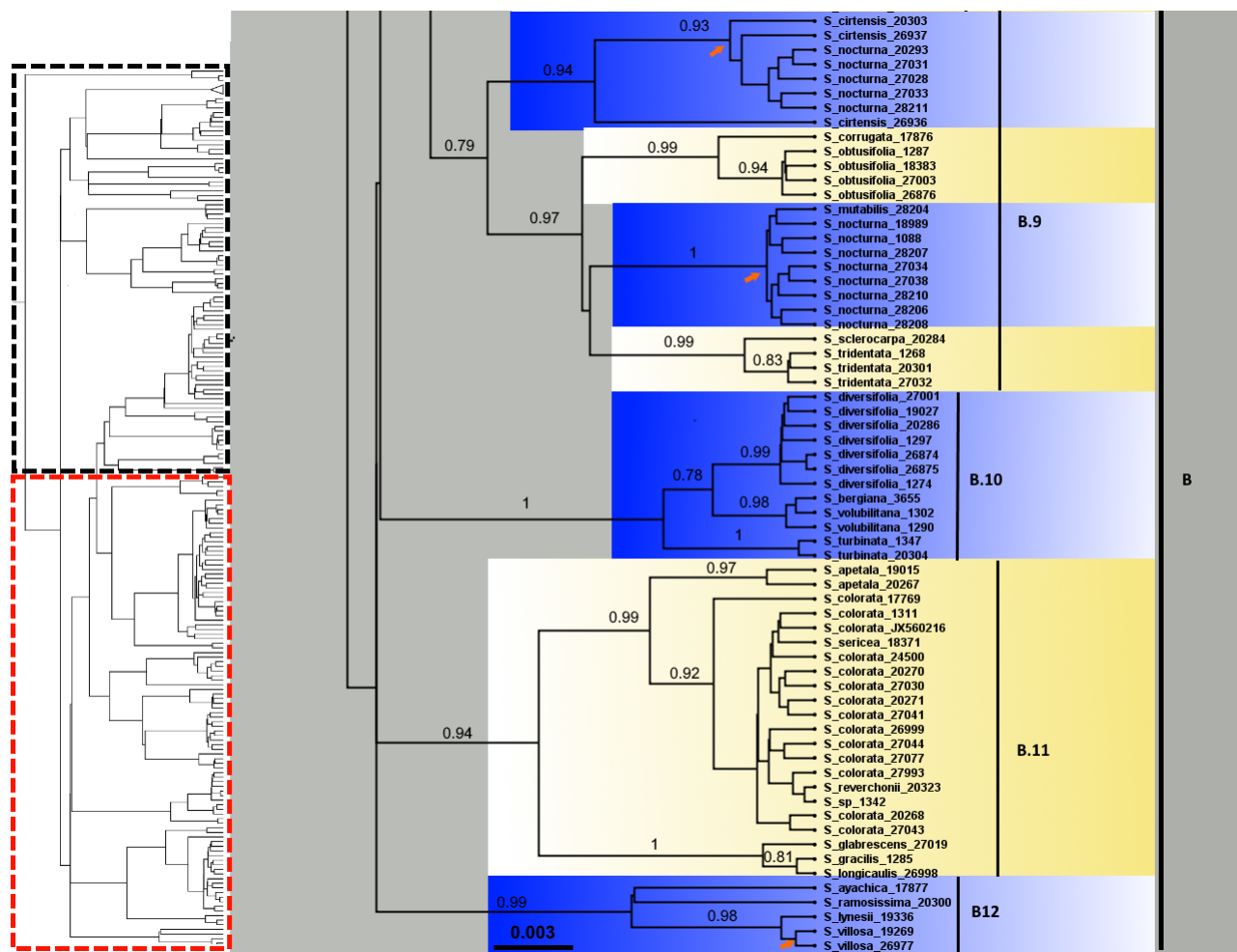


FIGURE 37 – Multiple Species Coalescent or Minimal Cluster (SMC) tree based on the nrDNA (ITS) and cpDNA (rps16) alignments of *Silene*. Posterior probability values ≥ 0.70 are indicated above branches. Taxon names are followed by specimen ID created using *Silene* database. Clade B11 will be discussed in the presentation, blue and yellow colouring shows the strongly supported clades. Red arrows point to the clades with nomenclatural ambiguities.

16 Utilisation du LiDAR terrestre et du Drone pour la quantification de la biomasse aérienne : cas des savanes du Centre Cameroun

Author	Gislain II MOFACK
Mail	mgislain2@yahoo.fr
Supervisors	Nicolas BARBIER, UMR AMAP, Montpellier, France, Pierre COUTERON, UMR AMAP, Montpellier, France, Bonaventure SONKE, UY1, Cameroon
Keywords	Biomasse ; Cameroun, Drone, Lidar terrestre, Savanne, photogrammétrie

La quantification de la biomasse aérienne (AGB) est indispensable pour une action climatique efficace. Pourtant, les modèles allométriques actuels d'estimation AGB présentent plusieurs inconvénients liés au choix du modèle et aux incertitudes concernant les estimations à large échelle. Le balayage laser terrestre (TLS) combiné à la photogrammétrie par drone offre une alternative non-destructive prometteuse en savane. Le volume des arbres est reconstruit à partir de nuages de points TLS avec des modèles de structure quantitative (MSQ) et converti en AGB via la densité du bois corrigée. Des modèles allométriques de biomasse sont ensuite calibrés sur les paramètres TLS facilement mesurables sur les nuages de points drone. Notre objectif étant (i) de développer des allométries non destructives pour les savanes du Cameroun, (ii) d'estimer la biomasse aérienne sur une superficie plus large pour la même strate. Dans le Centre du Cameroun, 5 parcelles de savane de $40m \times 40m$ sont entièrement scannées avec le LiDAR terrestre et 18 parcelles d'inventaires sont utilisées pour les comparaisons à large échelle. Le traitement des nuages de points obtenus permet d'avoir des volumes assez précis de tous les individus de chaque parcelle. Des allométries non destructives ajustées à ces valeurs de biomasse sont ainsi produites. Nos meilleures équations sont : (4) $AGB = e^{-10.065+1.056*\log(DBH*H*WD)}$ pour les paramètres classiques et (6) $AGB = e^{-6.9+0.93*\log(Sh*H)}$ pour les paramètres drone. Ces équations estiment la biomasse pour la strate étudiée avec une erreur comparable aux erreurs obtenues à partir des équations de la littérature. L'équation (6) utilisée pour l'estimation de la biomasse à l'échelle du paysage permet d'obtenir des erreurs de l'ordre de -40% pour la biomasse des arbres par rapport au modèle générique de référence. Les données lidar terrestre combinées au nuage de point dense drone sont une alternative prometteuse pour la quantification de la biomasse aérienne en savane.

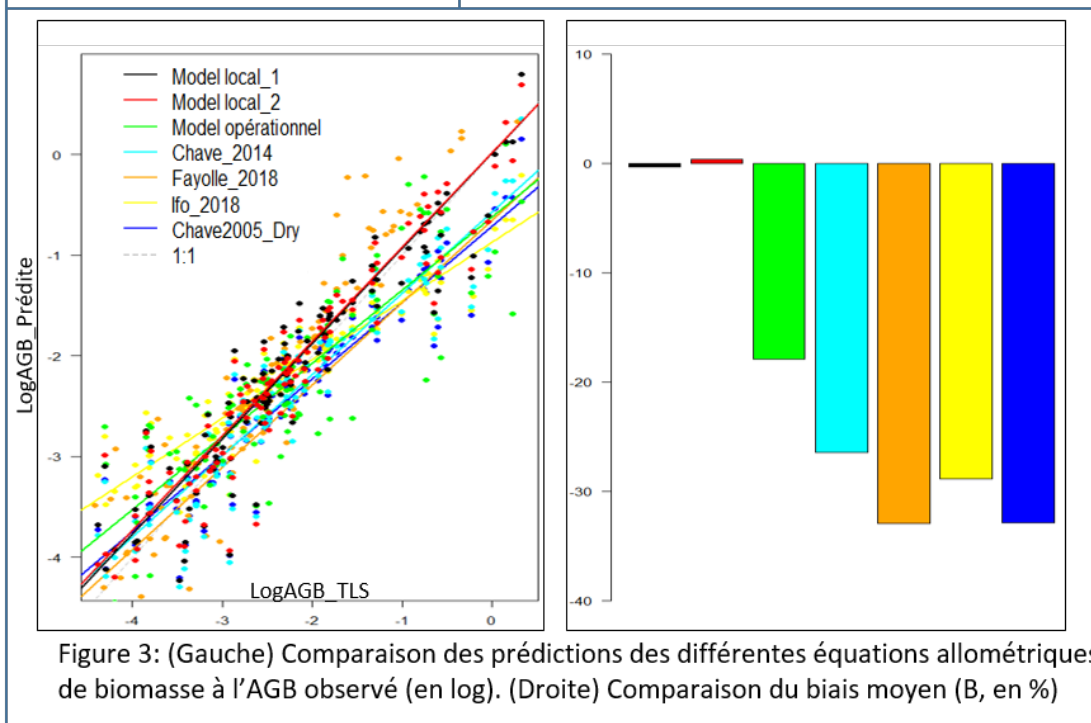
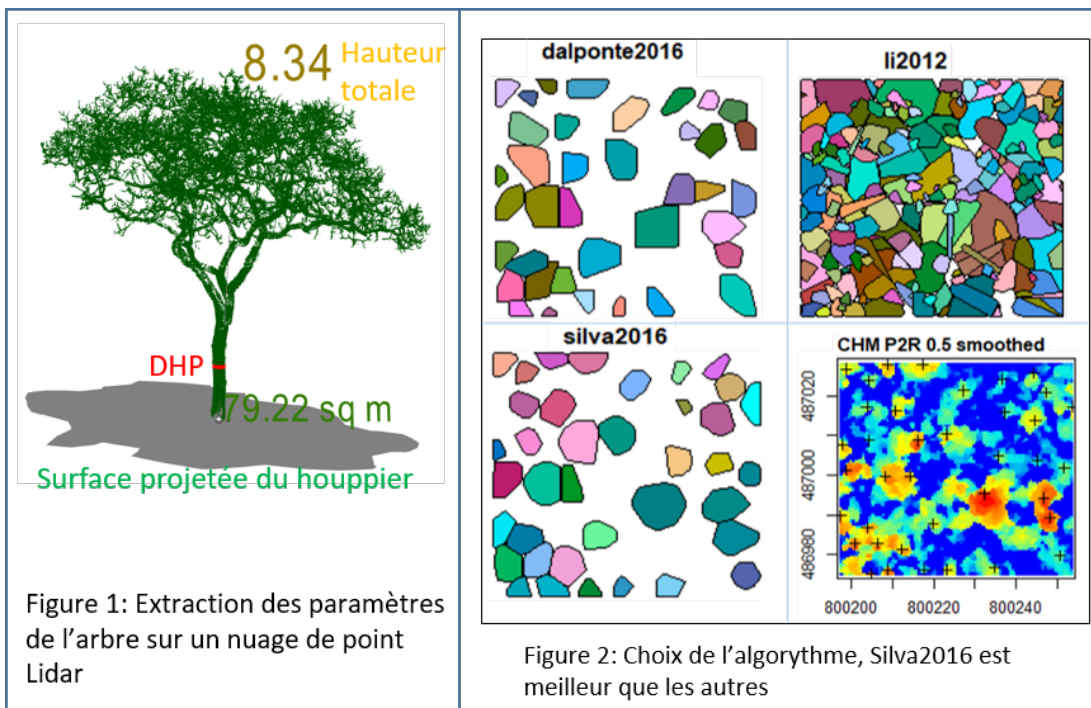


FIGURE 38 – Illustrations Ghislain II MOFACK

17 Dynamique spatio-temporelle des forêts à Marantacées d'Afrique centrale

Author	Juliette PICARD
Mail	juliette.picard@ird.fr
Supervisors	Maxime REJOU-MECHAIN, Sylvie GOURLET-FLEURY, Pierre COUTERON
Keywords	Tropical forest, Marantaceae, Central Africa, Spatio-temporal dynamics

Les forêts à Marantacées sont des formations d'apparence dégradée couvrant de très vastes zones en Afrique centrale. Elles ont une très faible densité d'arbres avec un sous-étage dense composé d'herbacées géantes et semblent très stable dans le temps. Le projet de thèse vise à étudier les mécanismes par lesquels ces forêts apparaissent et se maintiennent à différentes échelles spatiales et temporelles. Nous viserons à mieux comprendre la dynamique à long terme des forêts à Marantacées, les conditions dans lesquelles une stabilité est attendue et les mécanismes par lesquels des herbacées géantes peuvent monopoliser l'espace et les ressources tout en restreignant le recrutement et la croissance des arbres. Pour cela, diverses questions seront abordées, en partenariat avec les membres des projets DESSFOR et Paysage Nord Congo :

- quantifier l'empiètement des herbacées géantes suite à l'exploitation forestière (concession forestière de la CIB, Loundoungou),
- mesurer les effets des feux sur la dynamique des forêts à Marantacées (concession forestière d'IFO, Ngombé),
- mettre en évidence les effets des perturbations sur la reproduction des Marantacées : cela favorise-t-il la reproduction asexuée plutôt que sexuée ?
- dissocier les effets de la compétition Marantacées/arbres de ceux de l'allélopathie sur la régénération des ligneux,
- explorer la dynamique spatio-temporelle à long terme, dans le passé, des forêts à Marantacées (phytolithes, datation au 13C et 14C et quantification de la masse de charbon de bois).

Pour tenter de trouver des réponses, des inventaires seront menés dans les forêts du Nord Congo et une « culture » de Marantacées ex situ sera mise en place.

Figure 1.1 A dense *M. macrostachyum* patch in the Ndakan study Republic.



Figure 4.10 Photo taken in July 1999 in a *M. macrostachyum* patch that had been razed by elephants. Short *M. macrostachyum* leaves are re-emerging from underground rhizomes.



Figure 4.11 Same perspective three months later in October 1999. Other species of plants are present.



Figure 4.12 Same perspective in July 2000, one year after original photo was taken. *M. macrostachyum* has completely re-dominated the gap and leaves are almost up to full height. Note the man standing in the middle of photo.



Figure 5.1 Photo of whole-plant structure of *M. macrostachyum*. Label in photo is approximately 10 cm across.





Figure 25 : Exemples de forêts mixtes de terre ferme : a) Formation arborée à Marantaceae et *Aframomum*, cf. *subsericeum*, b) Forêt dense à Marantaceae (lisière), c) Forêt clairsemée à *M. macrostachyum*, d) Forêt dense humide semi-décidue à *T. scleroxylon* (et à sous-bois ligneux dense).

FIGURE 40 – Image provenant de la thèse de Gillet (2013)

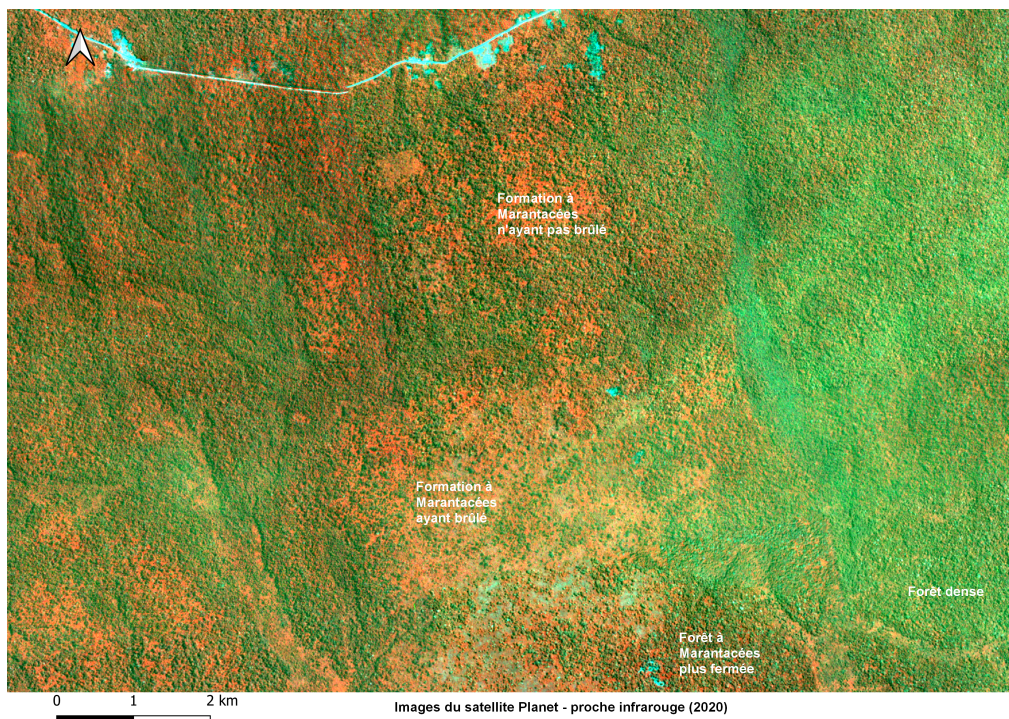


FIGURE 41 – Image réalisée par Juliette PICARD

18 Leveraging high resolution spaceborne data to monitor tropical forests phenology

Author	Pierre PLOTON
Mail	pierre.ploton@ird.fr
Supervisors	Raphaël Pélissier, UMR AMAP, Montpellier, France
Keywords	tropical forests, phenology, remote-sensing, time-series

Forest phenology (FP) – which reflects the temporal patterning of recurring biological events (leafing, flowering, fruiting) – influences the global dynamics of climate, carbon and water and is a marker of climate change at both short time scale (e.g. delay in species phenological events) and long time scale (e.g. shift in forest species composition). Intensification of global climate change and anthropogenic pressures on forests, notably in the tropics, is expected to modify their phenology, with ensuing consequences on their functioning and services. Monitoring tropical FP is thus a key scientific stake. Recent advances in the field of remote sensing, in particular the analysis of time series of satellite images with high spatial resolution, open new avenues for broad-scale monitoring of FP and forest functional composition (e.g. increase in heliophilic and / or deciduous species). Indeed, high-resolution satellite sensors now offer a spatial resolution (10 - 30 m) and a temporal frequency (5 - 16 days) sufficiently close to the scales of the objects (trees, stands) and processes (phenology) of interest to make it possible to control their links with the remote sensing signal, and ultimately to generate coherent extrapolations at broad scales (regional, global). The general aim of my project is to mobilize these tools to better understand, monitor and anticipate changes in the tropical FP at the scale of large forest basins. This requires analyzing hundreds of satellite images distributed in space and time, making images preprocessing (i.e. the removal of atmospheric, instrumental and acquisition effects) an essential step to warrant the spatiotemporal consistency of the radiometric signal, and in fine of model predictions. As a preliminary study, we used a set of Sentinel-2 images acquired at the same date over central Africa to fine-tune image processing-chain. Images were corrected for atmospheric and instrumental effects using state-of-the-art preprocessing model (i.e. Overland, from Airbus Defense and Space). Apparent residuals instrumental effects on corrected images (Fig. 42) were removed using a Fourier filter and linear intercalibrations of image bands were performed to improve the spatial consistency of the remote-sensing signal. We further used a set of c. 65 1-ha forest plots distributed over the area to assess the relationship between output images reflectance and forest stand phenology, defined as the basal-area weighted proportion of deciduous species within plots. Preliminary results suggest even with single-date Sentinel 2 images, stand phenology can be predicted with moderate-to-high confidence at 1-ha scale (Fig. 43)

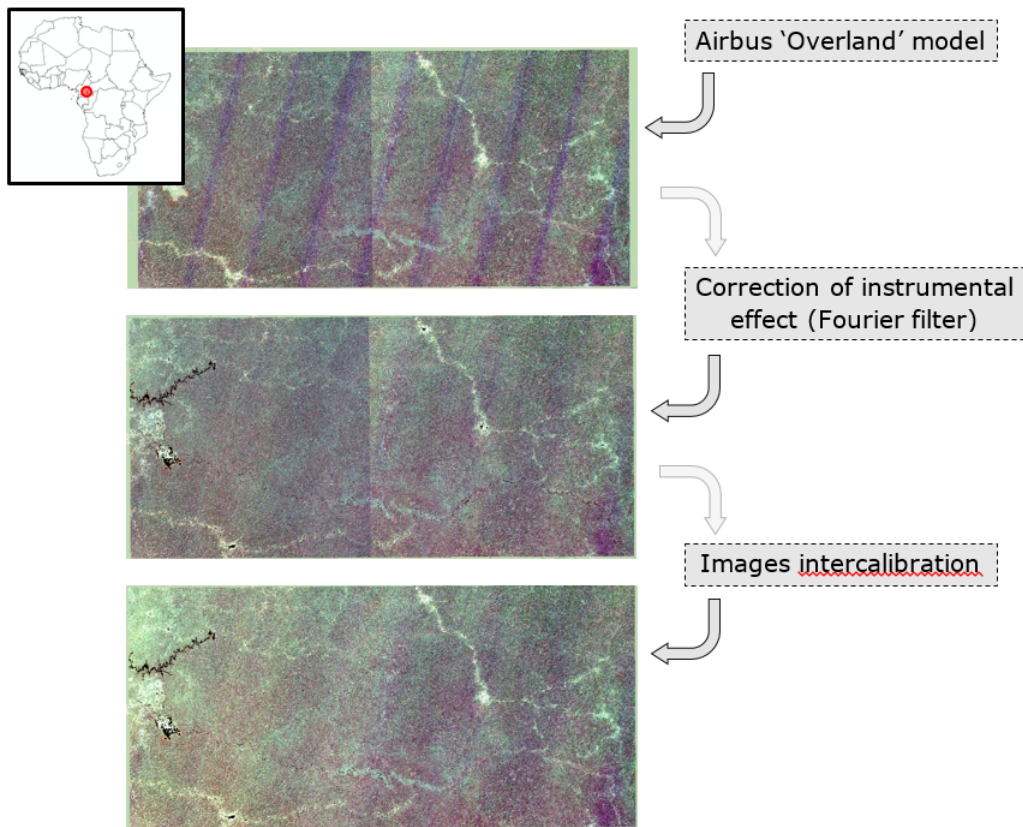


FIGURE 42 – Location of the study area and image preprocessing outputs.

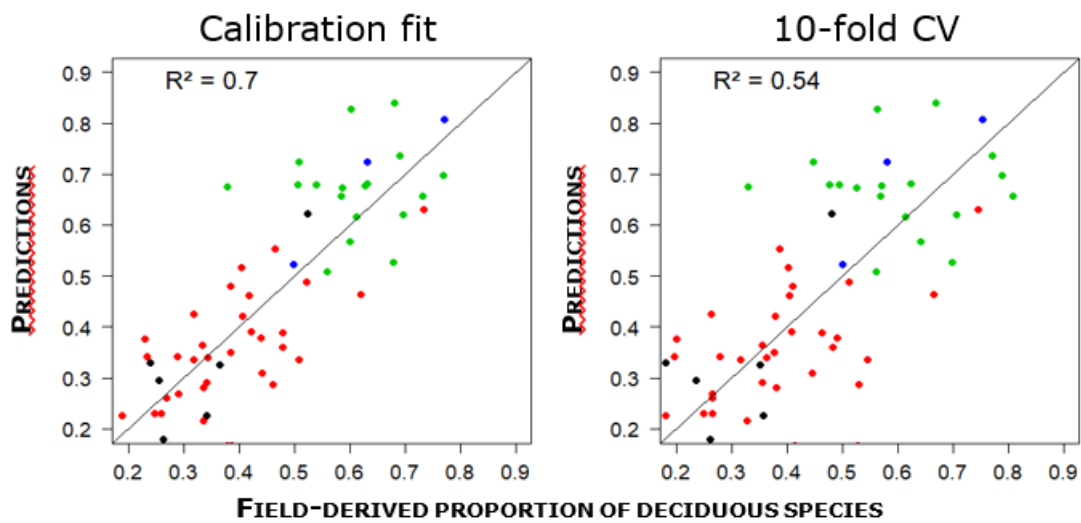


FIGURE 43 – Predicted vs field-derived stand deciduousness.

19 The adaptative significance of monocarpy in woody perennial plants : investigation around the genus *Cerberiopsis*

Author	Camille SALMON
Mail	camille.salmon@cirad.fr
Supervisors	Patrick HEURET, Sandrine ISNARD
Keywords	Monocarpy, Growth Rings, Tension Wood, Cyclones

Monocarpy designs a life history in which a single great effort of sexual reproduction is directly associated with the death of the entire plant. In trees, long-lived branched woody plants, this life strategy is rare and considered as an evolutionary bottleneck [26]. We introduce in this study a new type of growth wood ring in *Cerberiopsis candelabra* (Apocynaceae), a monocarpic tree endemic to New Caledonia [27].

Six adult individuals were sampled in contrasting habitats. Wood discs were collected at the base of the trunk, at 1.30-meter height and under each distinctive branch stage of the crown. These samples were analyzed at the SilvaTech Platform in Nancy. We performed for each sample (i) transverse and longitudinal anatomical sections, (ii) macrodensitometric analyses (tomography- Brightspeed Exel 4 X-ray scanner) and (iii) microdensitometric analyses (radiography - X-ray Itrax multiscanner). The wood anatomy was described according to the InsideWood classification.

We highlight the presence of wood growth rings marked by the periodic production of circular tension wood in *C. candelabra* (Fig. 44). We observe in the opposite wood ("regular" wood) the presence of xylem bands whose fibers present a gelatinous layer (G-layer) characteristic of tension wood. The annual rings are distinctly delimited by a thin band of tangential parenchyma indicating that the tension wood is produced periodically each year (Fig. 45).

We discuss the adaptive potential of regular tension wood production in *C. candelabra*. In angiosperms, tension wood is generally produced on axes under mechanical constraints in order to regain their verticality after a disturbance (windthrow, strong winds, cyclones, etc. [28]). *C. candelabra* (Fig. 46) is an endemic tree of New Caledonia, an archipelago exposed to annual cyclonic events. Periodic production of tension wood could lower the risk of trunk breakage due to turbulent winds and therefore increase the probability of pre-flowering survival, an essential condition for the maintenance of the monocarpic strategy in trees [29].

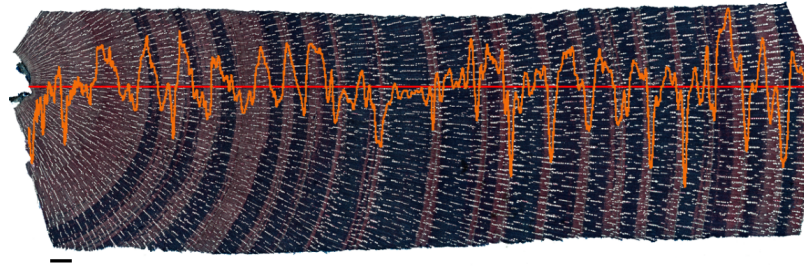


FIGURE 44 – Microdensitometric profile (orange curve) realized along the radius (red line) of a transverse anatomical section of the trunk of *C. candelabra* at 1.30 meter height. 22 growth rings are identified. The three oldest growth rings (first produced) do not present a tension wood band.

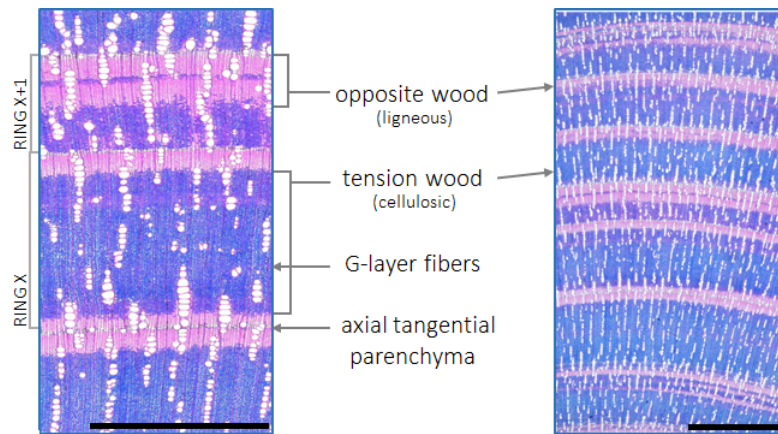


FIGURE 45 – Identification of the main anatomical elements composing a wood growth ring in *C. candelabra*



FIGURE 46 – Massive flowering of a stand of *C. candelabra* in Mouirange (New Caledonia) 12 weeks after the passage of cyclone Niran (category 5) in March 2021

20 Model checking ecological state transition graphs

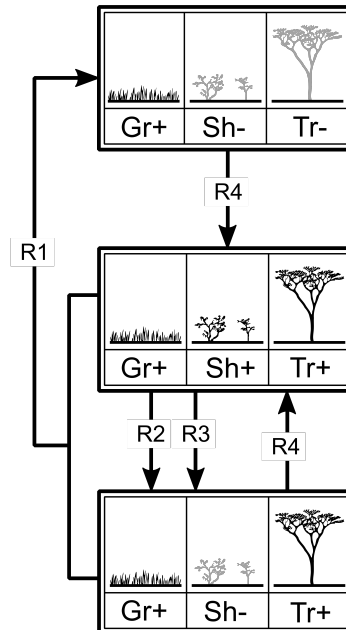
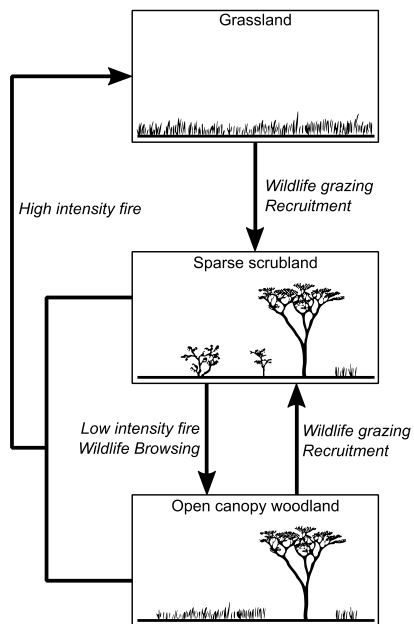
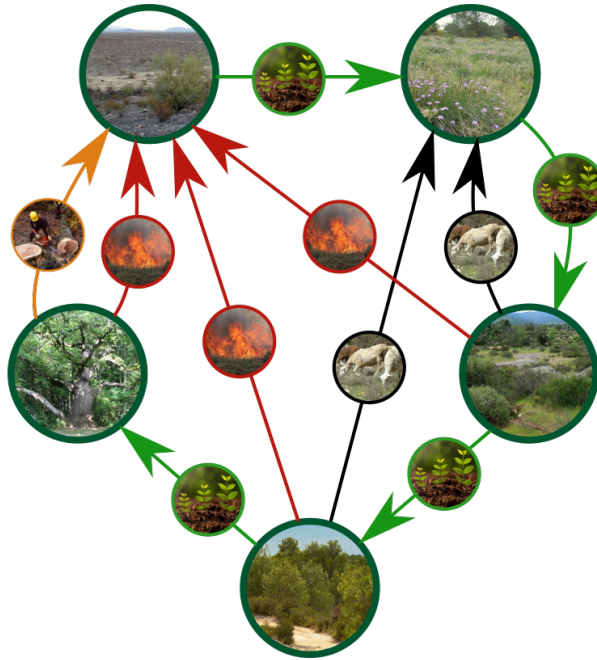
Author	Colin THOMAS
Mail	colin.thomas@cirad.fr
Supervisors	Franck POMMEREAU, UMR IBISC, Evry, France Cédric GAUCHEREL, UMR AMAP, Montpellier, France
Keywords	State and Transition models ; Ecosystem dynamic ; Succession ; Community assembly ; Model checking

The dynamic of an ecosystem can be represented by a state and transition graph : a set of nodes and edges linking the possible states of the ecosystem (see the figures below for examples). From the early studies on plant community succession [30] to the management of natural park in the USA [31], this formalism is usually used as a representation of empirical data. We propose to generate such state and transition graphs from a model based on discrete events. Those models generate huge graphs (thousands or millions of states) that require specific analysis. The lack of analysis tools may also be responsible of the absence of detailed state and transition graph based on empirical data [32].

Such formalism has been used for decades in computer science to represent the possible executions of a software. The state and transition graph is generated from the source code, and is tested against some specifications. The usual approach, called model checking, tests if a bug can happen during the execution of the computer program (for example if the Ariane navigation software can force the space shuttle to aim the ground). Those methods are able to test complex properties on state and transitions graph up to millions of nodes.

The main objectives of this thesis are :

1. To apply model checking methods to ecosystem state and transition graph, in order to test if the trajectories of the ecosystem always verify a given property (by analogy with the absence of bug).
2. To develop a new analysis tool representing the differences between “buggy” and “bugless” executions (computer science focuses on the presence or absence of bugs, while ecology is interested in the causes of the branching between different trajectories).



Variables :

Gr : grass
Sh : shrubs
Tr : trees

Ruleset :

[High Fire]
R1 : Gr+ >> Tr-, Sh-
[Low Fire]
R2 : Gr+ >> Sh-
[Browsing]
R3 : Sh+ >> Sh-
[Grazing + Recruitment]
R4 : Gr+ >> Sh+, Tr+

21 Linking structural traits, non-structural carbohydrate and tree ecological strategies in different climates

Author	Guangqi ZHANG
Mail	zh.guangqi@gmail.com
Supervisors	Alexia STOKES, UMR AMAP, Montpellier, France Pascale MAILLARD, UMR SILVA, Nancy, France Zhun MAO, UMR AMAP, Montpellier, France.

Functional traits have been examined in detail for several tree organs, but the relationship between traits, successional gradient and ecological strategies is poorly understood. The concept of an economics spectrum is currently used to describe the investment of a given species into different organs, depending on their position along an ecological succession gradient. It is now necessary to link functional traits of trees with knowledge of their ecological strategy and test whether similar strategies exist across different biomes. Results will help us better understand how different tree species can quickly colonise disturbed land, or maintain a position as a climax species in the canopy. Pioneer species that colonise a site rapidly must also mobilise energy from stored non-structural carbohydrates (NSC), which are stored in parenchyma cells. Nevertheless, climax species need to maintain their position in the canopy and may require large quantities of NSC and parenchyma for defence mechanisms. Moreover, study shows that the amount of axial parenchyma is related to vessel diameter and species with a high axial parenchyma fraction tend to have wide vessels, with most of the parenchyma packed around vessels. As yet, no specific relationships between ray parenchyma and any other anatomical traits (such as vessel size or density) have been found. Nor is it known if there is a relationship between ray parenchyma and ecological strategy of a species. A meta-analysis of existing data on functional traits, parenchyma volume and NSC will be performed to help disentangle relationships between all parameters. Extra analyses will be performed in the field along successional gradients (pioneer and climax) in three biomes (tropical rainforest, Mediterranean garrigue and temperate montane). A full characterization (climate, vegetation and soil variables) will be performed at each field site and 20 tree species per biome will be examined at the end of growing season, with three replicates per tree. The final outcome aims to find links between tree traits, carbohydrate supply and allocation and ecological strategies with regard to successional status in different biomes.

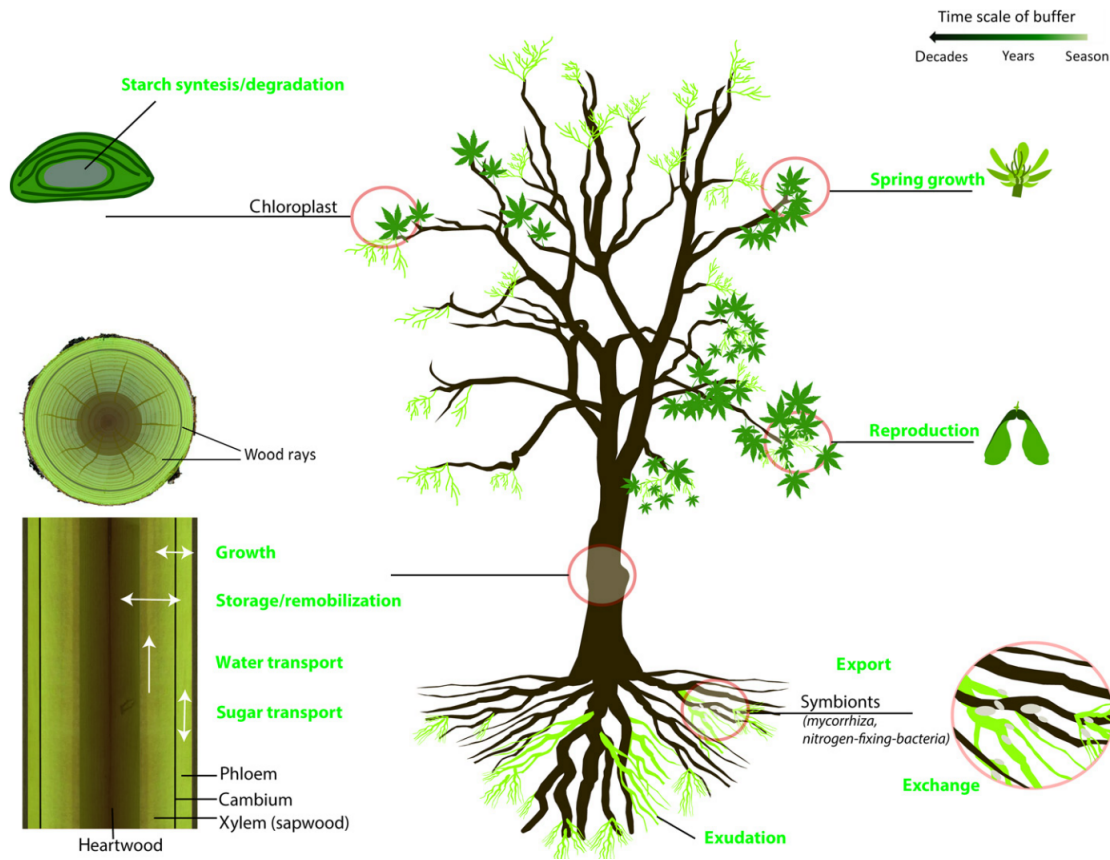


FIGURE 47 – Storage sites within the tree body, functional roles of nonstructural carbohydrates (NSC) and their temporal scales [33].

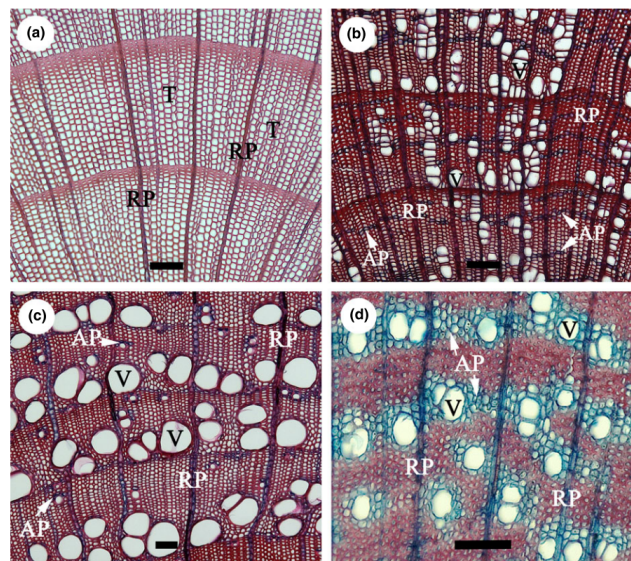


FIGURE 48 – Light microscopy images of transverse sections of conifer and angiosperm stem wood with different parenchyma fractions and spatial distribution [34].

Références

- [1] Hans TER STEEGE et al. “Hyperdominance in the Amazonian tree flora”. In : *Science* 342.6156 (2013).
- [2] Daniel W O’NEILL et al. “A good life for all within planetary boundaries”. In : *Nature sustainability* 1.2 (2018), p. 88-95.
- [3] Mohammed ALAMGIR et al. “Economic, socio-political and environmental risks of road development in the tropics”. In : *Current Biology* 27.20 (2017), R1130-R1140.
- [4] Jean-Baptiste FÉRET et Gregory P ASNER. “Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy”. In : *Ecological Applications* 24.6 (2014), p. 1289-1296.
- [5] Etienne LALIBERTÉ, Anna K SCHWEIGER et Pierre LEGENDRE. “Partitioning plant spectral diversity into alpha and beta components”. In : *Ecology letters* 23.2 (2020), p. 370-380.
- [6] Claude EDELIN. “Édelin, Claude, 1984. L’architecture monopodiale : l’exemple de quelques arbres d’Asie tropicale”. These de doctorat. Montpellier 2, 1984.
- [7] Daniel BARTHÉLÉMY. “Architecture et sexualité chez quelques plantes tropicales : le concept de floraison automatique”. These de doctorat. Montpellier 2, jan. 1988. URL : <http://www.theses.fr/1988MON20192>.
- [8] David WARTON et al. “So Many Variables : Joint Modeling in Community Ecology”. In : *Trends in Ecology & Evolution* 30 (2015), p. 766-779. DOI : 10.1016/j.tree.2015.09.007.
- [9] Otso OVASKAINEN et al. “How to make more out of community data ? A conceptual framework and its implementation as models and software”. In : *Ecology Letters* 20.5 (2017), p. 561-576. ISSN : 1461-0248. DOI : 10.1111/ele.12757.
- [10] James S. CLARK et al. “Generalized joint attribute modeling for biodiversity analysis : median-zero, multivariate, multifarious data”. In : *Ecological Monographs* 87.1 (2017), p. 34-56. ISSN : 1557-7015. DOI : 10.1002/ecm.1241.
- [11] Nick GOLDING, Miles A. NUNN et Bethan V. PURSE. “Identifying biotic interactions which drive the spatial distribution of a mosquito community”. In : *Parasites & Vectors* 8.1 (juil. 2015), p. 367. ISSN : 1756-3305. DOI : 10.1186/s13071-015-0915-1.
- [12] Maximilian PICHLER et Florian HARTIG. “A new method for faster and more accurate inference of species associations from big community data”. In : *arXiv :2003.05331 [q-bio, stat]* (juil. 2021).
- [13] Jérôme GUÉLAT et Marc KÉRY. “Effects of spatial autocorrelation and imperfect detection on species distribution models”. In : *Methods in Ecology and Evolution* 9.6 (2018), p. 1614-1625. ISSN : 2041-210X. DOI : 10.1111/2041-210X.12983.
- [14] David P. WILKINSON et al. “A comparison of joint species distribution models for presence-absence data”. In : *Methods in Ecology and Evolution* 10.2 (2019), p. 198-211. ISSN : 2041-210X.
- [15] James W DALLING et al. “Resource-based habitat associations in a neotropical liana community”. In : *Journal of Ecology* 100.5 (2012), p. 1174-1182.
- [16] Gerardo AVALOS, Stephen S MULKEY et Kaoru KITAJIMA. “Leaf optical properties of trees and lianas in the outer canopy of a tropical dry forest”. In : *Biotropica* (1999), p. 517-520.
- [17] Marco D VISSER et al. “A host-parasite model explains variation in liana infestation among co-occurring tree species”. In : *Journal of Ecology* 106.6 (2018), p. 2435-2445.
- [18] William F LAURANCE, Jeffrey SAYER et Kenneth G CASSMAN. “Agricultural expansion and its impacts on tropical nature”. In : *Trends in ecology & evolution* 29.2 (2014), p. 107-116.

- [19] Geertje MF VAN DER HEIJDEN, Jennifer S POWERS et Stefan A SCHNITZER. “Lianas reduce carbon accumulation and storage in tropical forests”. In : *Proceedings of the National Academy of Sciences* 112.43 (2015), p. 13267-13271.
- [20] Stefan A SCHNITZER et Walter P CARSON. “Lianas suppress tree regeneration and diversity in treefall gaps”. In : *Ecology letters* 13.7 (2010), p. 849-857.
- [21] Jeffrey J GERWING et al. “A standard protocol for liana censuses 1”. In : *Biotropica : The Journal of Biology and Conservation* 38.2 (2006), p. 256-261.
- [22] David B CLARK et Deborah A CLARK. “Distribution and effects on tree growth of lianas and woody hemiepiphytes in a Costa Rican tropical wet forest”. In : *Journal of Tropical Ecology* 6.3 (1990), p. 321-331.
- [23] Casey J COX et al. “Liana cover in the canopies of rainforest trees is not predicted by local ground-based measures”. In : *Austral Ecology* 44.5 (2019), p. 759-767.
- [24] Christian DUPRAZ et Fabien LIAGRE. *Agroforesterie : des arbres et des cultures*. France Agricole Editions, 2008.
- [25] Joseph ALCAMO et al. “Ecosystems and human well-being : a framework for assessment”. In : (2003).
- [26] Lourens POORTER et al. “A monocarpic tree species in a polycarpic world : how can *Tachigali vasquezii* maintain itself so successfully in a tropical rain forest community ?” In : *Journal of Ecology* 93.2 (2005), p. 268-278.
- [27] Jennifer READ et al. “Does tree size influence timing of flowering in *Cerberiopsis candelabra* (Apocynaceae), a long-lived monocarpic rain-forest tree ?” In : *Journal of Tropical Ecology* 22.6 (2006), p. 621-629.
- [28] Bruno CLAIR et al. “Tension wood and opposite wood in 21 tropical rain forest species”. In : *Iawa Journal* 27.3 (2006), p. 329-338.
- [29] Kaoru KITAJIMA et Carol K AUGSPURGER. “Seed and seedling ecology of a monocarpic tropical tree, *Tachigalia versicolor*”. In : *Ecology* 70.4 (1989), p. 1102-1114.
- [30] Frederic Edward CLEMENTS. *Plant succession : an analysis of the development of vegetation*. 242. Carnegie Institution of Washington, 1916.
- [31] Mark WESTOBY, Brian WALKER et Imanuel NOY-MEIR. “Opportunistic management for rangelands not at equilibrium.” In : *Rangeland Ecology & Management/Journal of Range Management Archives* 42.4 (1989), p. 266-274.
- [32] Brian WALKER et Mark WESTOBY. “Past, present and future of state and transition language”. In : *The Rangeland Journal* 42.1 (2020), p. 71-72.
- [33] Henrik HARTMANN et Susan TRUMBORE. “Understanding the roles of nonstructural carbohydrates in forest trees – from what we can measure to what we want to know”. In : *New Phytologist* 211.2 (2016), p. 386-403. ISSN : 1469-8137. DOI : 10.1111/nph.13955. (Visit  le 05/10/2021).
- [34] Hugh MORRIS et al. “A global analysis of parenchyma tissue fractions in secondary xylem of seed plants”. In : *The New phytologist* 209 (nov. 2015). DOI : 10.1111/nph.13737.