CEBA Annual Call for Proposals 2023

Grant Application Form

1. Administrative information

1.1. *Proposal title*:

Using Mobile LiDAR Scanning to characterise the micro-environment of tropical forest understorey.

1.2. *Acronym:*

MICROMETER : **M**obile L**i**dar **C**haracterise mic**RO**environ**ME**n**T** und**E**rsto**R**ey

1.3. *Name and contact information of the principal(s) investigator(s) (PI):*

First and last name:	Vincyane BADOUARD
Email:	vincyane.badouard@gmail.com
Full professional address: (including department/unit)	UMR 745 Écologie des Forêts de Guyane (EcoFoG) - Campus Agronomique - BP 316 - F-97379 Kourou cedex

1.4. *List of the participating labs/research units:*

- UMR 745 Écologie des Forêts de Guyane (EcoFoG), Kourou, France
- UMR 123 botAnique et Modélisation de l'Architecture des Plantes et des végétations (AMAP), Montpellier, France
- UMR 5174 Évolution et Diversité Biologique (edb), Toulouse, France

1.5. *Is one of the applicants a member of LabEx CEBA, or a member of a research team affiliated with CEBA in France?*

☑ YES ☐ NO

1.6. *Total support requested:*

15’000 €

2. Executive summary (max. ½ page)

The understorey is an essential compartment of the forest ecosystem as it hosts the young life stages of the trees that will constitute the future canopy. The understorey trees however are less studied than the canopy trees. Environmental heterogeneity occurring at small-spatial scale strongly influences the structure, composition, and functioning of tropical rainforests. Environmental filters particularly influence the establishment and survival of young individuals. The relative importance of different micro-environmental variables in shaping tree species distributions through their habitat preference and their regeneration niche however remains an open question, due to methodological limitations in the characterisation of the small-scale abiotic environment. In this project, we propose to address this knowledge gap and methodological limitation by using the innovative and promising LiDAR technology. LiDAR has already proven its ability to describe the 3D forest structure and topography on a fine scale. Forest structure and topography already allowed the prediction of important micro-climatic components for trees and notably light and associated air temperature and moisture as well as local drainage regime. LiDAR technology may also be able to predict other conditions essential to plant life: soil temperature, water and nutrient access. The LiDAR acquisition methods currently used to map forest structure have some limitations. Airborne laser scanning fails to describe the lower canopy in sufficient detail. Terrestrial laser scanning using fixed scan position below the canopy is limited in terms of its spatial coverage. The recent development of Mobile Laser Scanning (MLS), overcoming these limitations which make it the perfect candidate to assess understorey micro-environment. We therefore propose to describe the structure of the forest understorey with MLS and to compare its effectiveness in predicting micro-environmental variables with other techniques.

List 4-8 keywords that best describe the research area of your proposal:

1. Mobile LiDAR Scanning
2. Understorey
3. Micro-environment
4. Light
5. Temperature
6. Moisture
7. Soil
8. Topography

3. State of the art (max. 1 page)

The understorey is an important compartment of the forest ecosystem: it hosts the young life stages of the trees that will constitute the future canopy, as well as understorey specialists (*1*). The understorey cohort is however less studied than adult canopy and subcanopy trees. Environmental heterogeneity occurring at small-spatial scale strongly influences the structure, composition, and functioning of tropical rainforests (*2*). Environmental filters act throughout the tree life but particularly influence the establishment and survival of young individuals (*3*). The main environmental characteristics that drive tree establishment are the same that drive tree growth: light availability, temperature (*4*), and access to water and nutrients. The relative importance of different micro-environmental variables in shaping tree species distributions through their habitat preference and their regeneration niche however remains an open question, in part because of methodological limitations in the characterisation of the small-scale abiotic environment (*5*). This characterisation was initially carried out using protocols based on labour-intensive punctual measurements repeated throughout the study area (*6*). The development of automatic instruments able to autonomously collect and store measurements in the field have greatly improved the measurement capacity of field studies (*6*). The emergence of LiDAR in the late 1990s made it possible to map micro-topography and reproduce forest structure in 3D (*6*). Micro-topography has been shown to be a good proxy for soil fertility and soil water availability in French Guiana (*7*). The 3D structure allows the representation of the light extinction on a vertical gradient and hence the calculation of light availability, called transmittance, at any point in the forest (*8*).

Various methods of LiDAR acquisition can be used to describe the forest structure: airborne by aircraft (ALS) or drone (UAV), terrestrial fixed (TLS), and more recently terrestrial mobile (MLS). The Airborne Laser Scanning (ALS) provides spatially continuous and sub-metre-scale data from above the forest and across large areas (*9*). However, the price of the flight is high and the laser footprint size is in the order of decimetres. To address these limitations, Unmanned Aerial Vehicles (UAV) as drones are used to move the LiDAR at lower altitudes, on smaller areas thus increasing the spatial resolution (*10*). However, with aerial acquisition, the understorey remains poorly characterised due to the very strong attenuation of the laser signal at the bottom of the canopy (*11*). Terrestrial Laser Scanning (TLS) captures the understorey structure (*12*) and can complement aerial data (*13*). But TLS cannot easily cover large areas. Scanning one ha of dense tropical forest typically requires a week or two of intensive fieldwork as the scanner has to be moved from one scan location to the next (*14*). Another limitation due to TLS staticity, is that some parts of the forest are not scanned because they are hidden by elements closer to the scanner. This effect is called occlusion. As Mobile Laser Scanner (MLS) is moved by a person walking in the forest, it has the advantage to reduce occlusion by multiplying viewpoints (*15*). The MLS also allows rapid data collection and virtually unlimited number of scan-positions (*16*). MLS allows the forest to be scanned beyond the canopy for LiDARs of sufficient range, while producing a detailed 3D-representation of the understorey and micro-topography (*13*). Airborne (ALS and UAV) and fixed ground-based (TLS) LiDARs have already proven their ability to describe light, moisture and temperature, based on the topography and/or forest structure (*17*). While several studies have already highlighted the merits of MLS in characterising forest structure (*16*, *18*), to our knowledge no study has yet illustrated MLS predictive capacities of the micro-environment nor compared them with those of other LiDAR acquisition methods. We want to characterise the micro-environment in which trees establish themselves in order to better understand the environmental needs of trees and their sensitivity to environmental change. For that, we aim to firstly describe the understorey micro-environment with MLS, selected for its technical and practical advantages, and to compare the effectiveness of MLS with other techniques to provide a methodological comparison study.

4. Project description (max. 2 pages)

Objectives

This project aims to test an innovative method based on mobile LiDAR (MLS) to characterise the understorey micro-environment. It constitutes the first part of Vincyane Badouard's PhD whose objective is to identify the micro-environmental determinants of tree distribution in the understorey. It will address two questions: **Q1.** *How accurately can the forest structure and the topography described by LiDAR predict the spatial structuring of the understorey micro-environment?* **Q2.** *Can MLS scanning carried out in the understorey improve the assessment of micro-environmental (light, air and soil temperature, soil moisture and soil physical and chemical properties), as compared to above canopy measurements (ALS and UAV)?*

Scientific and technical program

We will use field-based measurements of environmental conditions as a ground-truthing to compare different LiDAR acquisitions, above canopy scanning (ALS and UAV) and below canopy scanning (MLS), acquired at the same time. The study site is located on plot 16 of the Paracou research station, French Guiana, where nine hectares of permanent inventory of all the trees bigger than one cm DBH have been established following ForestGEO inventory protocol (*19*).

LiDAR acquisition and LiDAR derived environmental variables - We will compare the results from two MLS with different ranges, which are the *Leica BLK2GO* and the *Hovermap ST-X*. The nine-hectare study area will be divided in 20 m x 20 m subplots in which MLS acquisitions will be made by walking in transects spaced at about five metres. We will also use ALS and UAV acquisition conducted in October 2023, ALS at 700 m altitude and 20-30 m for UAV set-up in such a way as to maximise lidar penetration. We will use LiDAR point clouds resulting from these four acquisitions to calculate topography (Digital Terrain Model (DTM) and 3D forest structure on the totality of the study area. From the DTM, we will calculate the Topographic Wetness Index (TWI), which characterises surface drainage and the associated water availability gradient and has been shown to correlate well at least at coarse scale (*20*). The 3D vegetation density and the light extinction coefficient (transmittance) will be calculated using the AMAPVox software (www.amapvox.org).

Field based micro-environment measurements - We will use 32 *HOBO* sensors and *Tomst TMS-4* sensors coupled along transects covering a topographic gradient (22 sensors in north - south direction) and two forest canopy opening gradients (10 sensors in east - west direction) to measure micro-environmental conditions for one year every 15 minutes. The *HOBO* sensors directly measure light (lumens/ft^2) and air temperature (°C) at one metre aboveground. *Tomst* sensors measure temperature (°C) at 8 cm depth into the soil, at the soil surface and 15 cm above the soil, and soil moisture at 14 cm depth. These continuous measurements will be complemented by punctual light measurement carried out using two coupled mobile field sensors (*LAI2200*): one placed at 1.3 m height within the understorey and a reference one placed in full light. For this, we will use two different designs: (i) following the gradient of the *HOBO* sensors but with a point every metre, and (ii) on two regular grids (2 m x 2 m) covering 10x10 m each: the first one in the understorey, the second one at the edge of a forest gap. The *LAI2200* optical sensor will allow calibrating/validating the light level derived from radiative transfer modelling applied to the 3D forest scene derived from the LiDAR data with the *AMAPVox* software (*8*).

We will study the following soil physical characteristics: bulk density, drainage type (qualitative description of soil horizons down to 1.2 m depth), Available Water Capacity (AWC), calculated from granulometry measured on 1.2 m soil cores using the Biljou method ('Modèle de bilan hydrique forestier' INRAE - UMR Silva). Chemical composition (exchangeable P, total C, N and P, available cations (K, Mg, Ca, Al, Mn, Na), CEC and pH) will be measured in the laboratory (CIRAD, Laboratoire d'analyses - CIRAD/PERSYST). We will follow standard protocols chosen to be adapted to edaphic conditions of

French Guiana and be comparable to previous studies, on soil samples collected between 0 and 30 cm depth (see Appendices for details). Soil samples were collected along a pronounced topographical gradient of the study area: bulk density and chemical characteristics on five samples from the plateau, two samples from the upper slope, two samples from the middle of the slope, two samples from the lower slope and five samples from the bottomland. Two 1.2 m cores (for drainage class characterisation) were made for each topographic class: plateau, slope and lowland (Appendices. Fig. A1).

Data analysis - We will assess the quality of environmental variables derived from LiDAR as proxy for micro-environmental features (Q1.). To do so we will use correlation tests, linear regressions and analyses of the coherence of spatial patterns including spatial autocorrelation and analysis of variance. To check if the MLS is the best LiDAR acquisition method to characterise the understorey micro-environment (Q2.), we will (i) perform spatial correlation tests and linear regressions between the different LiDAR methods, (ii) and map differences between variables obtained with the different LiDAR acquisition methods to identify areas of convergence/divergence. We will also explore the combination of airborne and ground-based LiDAR acquisition to refine the description of the forest structure and the resulting prediction of understorey micro-environment. To check if the MLS is also the best LiDAR acquisition method in terms of time and cost efficiency (Q2.), we will compare the costs and time required for each of the LiDAR acquisition methods.

Expected results

At the end of this project, we will provide a proof of concept and recommendations for field protocols regarding the use of MLS derived-data as a proxy for micro-environmental variables. We will additionally provide information on the costs and time allocated to each acquisition method. We will produce (i) data on forest structure (trees mapping, trees architecture, trees dimensions, Leaf Area Index (LAI), canopy gap fraction) at fine resolution by LiDAR acquisition, (ii) maps of fine topography, TWI, and light, and (iii) micro-gradients of light, temperature, soil moisture and physico-chemical characteristics of the soil in our study site at Paracou.

Timeline

This project has already started within the framework of Vincyane Badouard's PhD with the design of the collection protocols, and the set up of the field sensors measuring the micro-environmental data.

	2023												2024			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Protocols development	■															
Field sensors installation		■	■													
ALS, ULS, MLS and LAI2200 sensor acquisitions				■				■	■							
Data treatment and analysis				■	■	■	■			■	■	■	■	■	■	
Manuscripts preparation and project report																■

5. Integration within the scientific objectives of the LabEx CEBA (max. ½ page)

This project is consistent with the scientific objectives of LabEx CEBA through the "Ecosystem processes and biodiversity" component. Our research will contribute to the methodological development of understorey micro-environment characterisation by using for the first time the innovative MLS technology. We will acquire knowledge on the understorey micro-environment in the Guyanese forest. This project is also the first phase of a thesis that will use the results obtained to study the distribution of tree species with varying ontogenetic stages in the different micro-environments described. This project will ultimately lead to a better understanding of the influence of environmental filters on tropical rainforest trees through life stages, and thus allowing an estimation of their sensitivity to environmental changes. Understanding the effect of the micro-environment on community assembly also contributes to a better understanding of biodiversity in tropical rainforests, a key scientific objective of LabEx CEBA. The mobile terrestrial LiDAR acquires high-precision data that open many other applications that can widely benefit the CEBA community. For example, resulting point clouds can help the correction of tree spatialisation, the development of allometries of understorey trees, or the characterisation of leaf density by species and ontogenic stage, allowing, among others, to study tree growth strategies or forest carbon balance. A better understanding of micro-environmental heterogeneity (project) and its role in filtering tree community assembly (PhD) can be used to refine the dynamic of the understorey in forest simulators such as TROLL (*21*).

6. Consortium description

First and last name	***Affiliation***	***Email***	***Professional address***	***Qualification & Contribution***
Vincyane Badouard	Ademe	vincyane.badouard@gmail.com	EcoFoG	PhD student, PI Sampling, data analysis, writing
Grégoire Vincent	IRD	gregoire.vincent@ird.fr	AMAP	PhD, HDR, Remote sensing Data analysis
Eric Marcon	AgroParisTech	eric.marcon@agroparistech.fr	AMAP	PhD, HDR, Spatial statistics Data analysis
Géraldine Derroire	Cirad	geraldine.derroire@cirad.fr	EcoFoG	PhD, Tropical forest ecology Data analysis
Giacomo Sellan	Cirad	giacomo.sellan@cirad.fr	EcoFoG	PhD, Ecology and botany Sampling
Pierre-André Wagner	Lycée Agricole de Matiti	pierre-andre-.wagner@educagri.fr	Lycée Agricole de Matiti	PhD, Soil science Sampling, data analysis
Jérôme Chave	CNRS	jerome.chave@univ-tlse3.fr	edb	PhD, HDR, Ecosystem modelling Sampling
Vincent Dehaye	CNRS	vincent.dehaye@univ-tlse3.fr	edb	Engineer Sampling, data analysis
Julien Lamour	CNRS	julien.lamour@univ-tlse3.fr	edb	PhD Sampling, data analysis

7. Budget

	Amount (€)	Justification
Material and Supplies*		
Mobile Laser Scanner rental (*Hovermap ST-X)* + software (1 month rental)	6 000	Characterise the light environment of the understorey
Laboratory analyses of soil (according to the price quotation)	7 000	Characterise the soil environment
HOBO light and temperature sensors x32	0	Characterise the light environment of the understorey Already acquired
Tomst moisture and temperature sensors x32	0	Characterise the soil moisture and temperature environment Already acquired
Travel and per diem		
Mission: air travel and living expenses	2 000	Training and data analysis in teams
Other costs**		
TOTAL AMOUNT REQUESTED	15 000	
Co-funding available		

8. References (max. 1 page)

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9. Appendices (max. 2 pages)

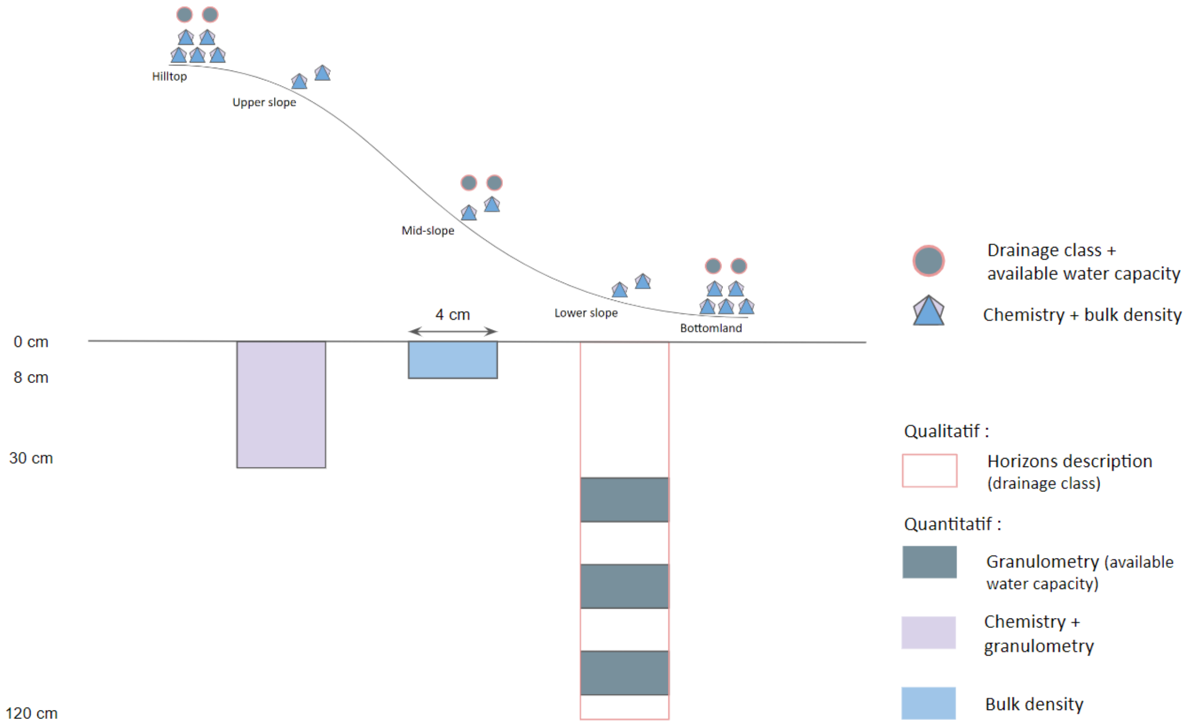

Fig. A1: Experimental design of the study of soil physico-chemical characteristics.

Soil protocol

The bulk density (g/cm^3) will be measured on soil samples of 250 cm^3 taken with an 8 cm deep cylinder. Each soil sample will be then dried at air condition, grinded with a 2 mm sieve and dried in a lab oven at 105°C for at least 48h. We will then weigh the sample and calculate the bulk density by dividing soil dry weight by soil volume. The drainage type is defined on the basis of the qualitative description of the soil horizons sampled by augering through a depth of 1.2 m. To estimate the AWC, three soil samples will be taken from the 1.2 m core previously taken for drainage type characterisation. These three samples will represent textural homogeneities and their granulometry will be measured in the laboratory (CIRAD, Laboratoire d'analyses - CIRAD/PERSYST). From these three measurements, the AWC will be estimated using the Biljou method ('Modèle de bilan hydrique forestier'. INRAE - UMR Silva). The soil elements selected for this study are exchangeable phosphorus (P, extracted with Bray1, indicated in case of acid soil as in French Guyana, and Olsen, often used in the literature and chosen here to allow comparison of our results with existing local literature, total C, N (quantified by gas chromatography), total P, available cations (K, Mg, Ca, Al, Mn, Na), CEC (extracted by Cobaltihexamine method at soil pH suitable for the study of soil-vegetation relationships) and pH (measured in a 1:2 solution with distilled water). These soil chemical characteristics will be quantified on soil samples taken between 0 and 30 cm depth by augering.