# USE OF TREE HEIGHT FOR MANGROVE SPECIES CLASSIFICATION

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**ABSTRACT:**

Mangrove forests play an important role in the balance of biodiversity. However, they are threatened by agriculture, aquaculture, urbanization and global warming. That's why it is imperative to monitor this ecosystem and understand how it evolves in the face of these threats in order to better preserve it. The traditional methods are invasive and time consuming. Besides, it is often difficult to get into mangroves because of the particular structure of some species, so measurements cannot be taken in those areas. That's why it is very interesting to use aerial data provided by unmanned aerial vehicles (UAVs) photos or airborne laser scanning systems (ALS). Moreover, some representative elements of mangroves are only a few tens of centimeters high. This is the case of pneumatophores. Traditional measurements would be much too long. In this case, it is interesting to use terrestrial laser scanning systems (TLS) to make measurements and to follow them. A research project began in 2021 to try to understand how urban mangroves develop in semi-arid regions, using remote sensing techniques (photogrammetry, airborne and terrestrial laser scanning). The purpose of this paper is first to present the project and the issues of monitoring mangrove forests. Then, it proposes a state of the art of the methodologies used to record mangrove. Finally, it presents the different acquisitions made as well as the first results of species classification based on photogrammetric point cloud processing. The assessment based on ground truth shows already promising results.

## 1. INTRODUCTION

### 1.1 Context

Mangrove is an ecotone represented by an association of trees, shrubs, debris and other halophytic plants often made up of anoxic sediments. It develops in hypersaline soils, following the tidal swing, in (sub)tropical, temperate climates or in arid and semi-arid regions where only few studies have been conducted (Adame et al., 2021). Mangrove play an important role in the environment with all the ecosystem services they provide. For example, wood is used for the construction of houses, boats, furniture or fishing tools (Numbere, 2018; Genilar et al., 2021). Mangrove can protect coasts against tsunamis, cyclones and storms (Alongi, 2008; Menéndez et al., 2020). It is a true natural habitat. It serves as a place of reproduction, nursery and development for many animals and plant species. It has important medicinal properties to fight against certain diseases and infections (Vinoth et al., 2019; Audah et al., 2020; Genilar et al., 2021). It is also a natural filter. Indeed, it has the capacity to filter water and to transform certain chemical substances into minerals beneficial to its growth. Finally, it is a so-called "blue carbon" ecosystem since it has the capacity to store a very large quantity of carbon and thus to participate in the regulation of the climate. Unfortunately, the benefits of mangroves and their development process are still not well known and this ecosystem is nowadays very threatened, especially by agriculture, aquaculture, urbanization or global warming. More than 35% of the world's mangroves have disappeared since 1950 (Valiela et al., 2001; Polidoro et al., 2010). It is therefore important to study and understand this ecosystem to better preserve it. Forest inventory is a very good way to monitor the evolution of a forest. It consists of determining the surface area, classifying different species, quantifying the number of trees and determine the structural parameters (tree height, trunk and crown diameters). The traditional methods used for forest inventories are invasive and time consuming. For example, to determine the soil elevation within the Heart of Voh, New Caledonia, Bourgeois et al. ( 2019) measured almost 5 200 points in about 2 days using a Differential Global Positioning System (DGPS). Besides, it is often difficult to get into mangroves because of the particular structure of some species, so measurements cannot easily be taken in those areas. Currently, the evolution of remote sensing tools allows us to acquire data more and more quickly and accurately, provided that operating procedures are adapted to the context.

### 1.2 The research project

Our research project aims to study the development of urban mangroves ecosystem in a semi-arid region using remote sensing methods (UAV and ALS). The use of terrestrial laser scanning (TLS) is also considered in our study to monitor individual trees and pneumatophores. This research project includes 2 main parts: a methodological part and an analysis and environmental part. The first objective is to set up an acquisition and adequate workflow to collect rapidly and with high frequency, precise information, like structural parameters, the soil elevation, the LAI (Leaf Area Index) and the delimitation of different species, for a regular monitoring. It consists in setting up a processing chain in order to extract from the point clouds obtained, all

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information necessary to understand the development and the evolution of the mangrove forests, i.e. areas, species classification and LAI at different scales, structural parameters (diameters of trunks (DBH), height of trees and volume of crowns). The automation of some tasks will be proposed in this project. The second objective is to interpret and analyse data to understand the development of mangroves. What is the link between the tidal swing, salinity and soil elevation? What is the impact of freshwater in mangroves? What is the impact of urbanization on the mangroves carbon storage?

## 2. RELATED WORKS

For several years, tools and techniques for monitoring forests have evolved. Indeed, the use of photogrammetry and TLS becomes more and more popular. This section presents main solutions for the data acquisition and possible processing chains developed for mangrove forests monitoring.

### 2.1 Acquisition systems for mangrove surveying

Data acquisition is a very important step. In the literature, several authors propose operating procedures to acquire the geometry of mangroves. Most of the time, they produce 3D point clouds to describe the geometry of the trees. The choice of the sensor, the operating procedure, as well as the choice of acquisition parameters will obviously influence the results obtained. That's why it is important to define an acquisition plan beforehand.

**2.1.1 Acquisition with laser scanning techniques:** Bauwens et al., 2016 compared a TLS, i.e. FARO Focus 3D 120 and a MLS (Mobile Laser Scanner), i.e. Zeb-1 with the aim to select the best system for mangrove monitoring. They observed that the major disadvantage of the TLS is the occlusion caused by the different shafts and that the MLS enables to alleviate this problem. However, it is very difficult to move while keeping a stable position inside a mangrove forest because of the obstacles (branches, roots, mud). Moreover, although the MLS has an inertial unit, it is necessary to move at a steady pace and ensure that the instrument remains relatively stable. That's why MLS is not suitable for mangrove inventory. TLS is a relatively large cumbersome instrument. Therefore, entering a narrow environment full of obstacles such as mangroves with a scanner remains very complicated.

**2.1.2 Acquisition with photogrammetric techniques:** To build a point cloud from aerial photographs, it is necessary to respect certain criteria (flight altitude, flight speed, overlaps and adequate weather conditions). For example, Fang et al. (2019) or Quirós and Khot (2016) present an algorithm to automatically count the number of apple trees. For this purpose, a flight altitude of between 10 and 25 m is recommended in order to minimize errors on the result. Perroy et al. (2017) also note the importance of flight altitude in identifying *Miconia* species in Hawaii. They show that the quality of the tree detection is strongly dependent on the flight altitude. The lower the flight altitude, the higher the image pixel resolution. Kameyama and Sugiura (2020) focus on the comparison of factors influencing the outcome of tree height determination (different altitudes, different overlaps). They modified 4 parameters (flight altitude, flight speed, lateral and longitudinal overlaps) and concluded that a minimum overlap of 90% is required. Moreover, to ensure high accuracy the authors suggest to fly at low altitudes (50-60 m). In their study, Santos Santana et al. (2021) investigate the influence of flight altitude and GCP distribution on the geroreferencing of the point cloud obtained from aerial photographs over an experimental area consisting of coffee crops at the University of Lavras, Brazil. They consider several altitudes (30 m, 60 m, 90 m and 120 m) in terms of number of images, pixel resolution and flight time and concluded that the altitude of 60 m provide best results. In summary, it is important to make a good compromise between a sufficient overlap, a low altitude flight and the number of photographs which influence not only the flight duration but also the processing time.

We have seen that depending on the tool used, several precautions must be taken in order to obtain accurate data. Two acquisition systems have been mentioned because they are the systems that are used in this project. A third system will be used in this project: the LIDAR system which has the particularity of being a multi-echo system allowing to acquire data from the canopy and the ground.

### 2.2 Extraction of mangrove characteristics for their monitoring

In our study, 4 characteristics which help to monitor mangroves have been selected: the species, the structural parameters, the LAI, and the pneumatophore parameters. There are several techniques to monitor mangrove forests. Depending on the acquisition method, (photogrammetry, TLS or ALS), several processing chains have been implemented in the literature to ensure the monitoring of forests using those characteristics.

**2.2.1 Mangrove species classification**: In the literature, it is possible to find species classification methods based on pixel based or object based classifiers (Kamal & Phinn, 2011; Heumann, 2011; Kamal et al., 2015). A pixel-based classification consists of comparing each pixel of an image with each other to form classes by grouping them together based on the spectral signature of each single pixel. An object-based classification uses in addition geometric and spatial context information (size, shape, adjacent objects). Kamal and Phinn (2011) compared both methods using CASI-2 data with a spatial resolution of 4 m and concluded that the object-based method performs better results than the pixel-based method with overall respective accuracies of 76% and 69%. As well, Cao et al. (2018) attempted to classify mangrove species using object-based image analysis techniques from hyperspectral images obtained from the UHD 185 sensor carried on a UAV platform. Using spectral and textural features as well as vegetation index and tree height, they showed that SVM (Support Vector Machine) image classification method was more accurate than the KNN (k-Nearest Neighbour) method with respective accuracies of 88.66% and 82.09%.

**2.2.2 Structural parameters from point clouds:** Bucksch et al. (2014) measure the diameter at breast height (DBH) of trees by first extracting each tree from the point cloud. The method for detecting DBH is based on calculating the point-skeleton distance as described in Rahman et al. (2009). It involves first extracting the stem from the tree skeleton and then determining the stem diameter by calculating the distance from each point to the center of the stem. Photogrammetric techniques do not allow to obtain structural information about the trees since the point cloud is generated from aerial photographs. Indeed, when the forest is dense, only the canopy can be captured. Thus, the structural parameters (tree height, trunk diameters, crown volume) might be determined more easily from data generated by airborne LIDAR, which has the particularity of sending multi-echo waves that can penetrate the vegetation. The point cloud obtained allows therefore to visualize the ground, the canopy and intermediate elements.

#### 2.2.3 LAI determination from remote sensing techniques:

LAI is a dimensionless quantity which expresses the leaf area of an ecosystem. It is a very good health indicator of a plant or a forest. There are several ways to estimate LAI. In their paper (Fang et al., 2019) resume methods for determining LAI using remote sensing. Vegetation indices (VI) are commonly used to estimate LAI. The normalized difference vegetation index NDVI (Kamal et al., 2016) or the soil-adjusted vegetation index SAVI (Biudes et al., 2014). The advantage of this method is its simplicity to implement, that's why most of the studies use satellite data to estimate LAI. However, (Hu et al., 2018) attempted to estimate LAI on an urban individual tree using an indirect measurement method from TLS data, i.e the path length distribution model. Their study shows that the density of the point cloud is correlated with the estimation of LAI.

#### 2.2.4 Determination of the pneumatophore parameters:

*Avicennia* have roots that develop laterally a few tens of centimeters below the ground. The organ on the surface is called "pneumatophore". Few studies have been done on this type of roots. To understand how *Avicennia* develop, Dicks (1986) observed that pneumatophores are more common in waterlogged and polluted soils than in well-drained and clean soils. Just as the structural parameters of trees, those of pneumatophores could give us essential information on the development of *Avicennia*. However, pneumatophores are small roots of about 10 centimeters in height and a few centimeters in diameters. They are not visible in point clouds obtained by photogrammetry. It is therefore necessary to determine them using a terrestrial laser scanner system.

Figure 1 shows the planned processing for determination of characteristics to monitore mangrove forests. The objective is to compare the acquisition methods and to define the most appropriate acquisition protocols. Then, depending on the data acquired, characteristics will be extracted to monitor mangrove forests. Species classification will be made from photogrammetric and ALS data. Structural parameters will be extracted from TLS and ALS data. Pneumatophores parameters will be obtained from TLS data and finally, LAI can be calculated from TLS, ALS and/or photogrammetric data.

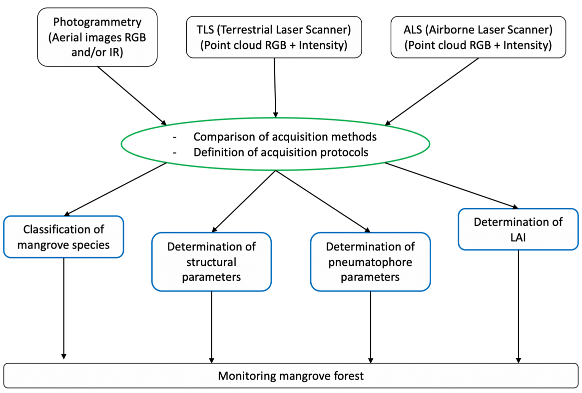


**Figure 1.** Workflow for characteristics determination allowing the monitoring of mangroves.

## 3. STUDY AREA AND DATA

### 3.1 Study area

The area under study in this project is located in Dumbea, on the west coast of New Caledonia where the climate is semi-arid. In this region, it can be observed that the salinity gradient increases with the elevation gradient (Figure 2). The study area measures about 19 ha (Figure 3) and it is mainly covered by *Avicennia Marina* and *Rhizophora* and more occasionally some *Bruguiera*. *Rhizophora* have the particularity to have stilted roots making difficult movements in mangrove (Figure 4).

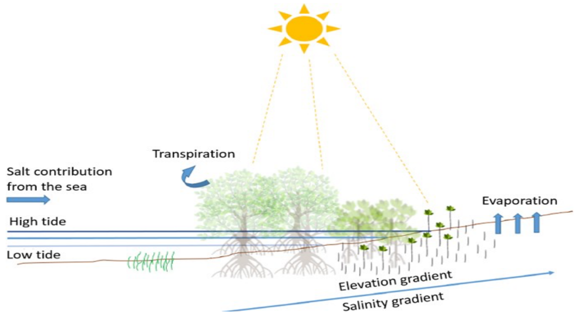


**Figure 2**. Simplified sketch showing the evolution of soil salinity according to the slope of the land.

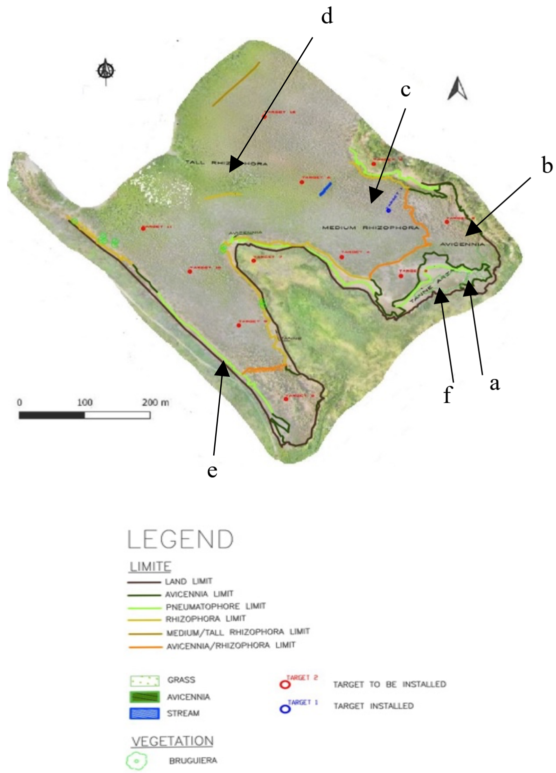


**Figure 3.** Topographic plan on an orthophoto. The red dots represent the targets that will be used for aerial photogrammetry. Arrows indicate (a) the tannin area, (b) the *Avicennia Stylosa*, (c) the medium *Rhizophora*, (d) the tall *Rhizophora*, (e) the pneumatophores and (f) the seagrass beds.

**Figure 4.** Picture showing the *Rhizophora* stilt roots.


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### 3.2 Data acquisition

Three acquisitions have been made since the beginning of the project: a field acquisition for collecting reference data (ground truth), an acquisition using UAV and another using a TLS. Acquisitions from UAV and TLS were organized to define a protocol.

**3.2.1 Field acquisition for DTM production:** A topographic survey was carried out over several days between December 2021 and January 2022 in order to produce a precise Digital Terrain Model (DTM). This DTM will be used as a ground truth for analysing the DTM which will be produced using photogrammetric and/or laser scanning techniques. The investigations allowed us to delimit the different major areas: (a) the tannin area, (b) the *Avicennia Stylosa*, (c) the medium *Rhizophora*, (d) the tall *Rhizophora*, (e) the pneumatophores and (f) the seagrass beds, (Figure 3). Acquisitions were carried out using a global positioning system (Trimble R8S, USA), providing the position of each point in real time. We connected to the New Caledonian banyan network using the VRS (Virtual Reference System). The final accuracy for each point is less than 2cm. Approximately 1 600 points were used to delimit the different areas and also to carry out a regular seeding. In the short term, a manual acquisition of structural parameters will be performed by creating measurement areas distributed in the mangrove forest.

**3.2.2 Data acquisition with UAV:** A first acquisition was carried out using the DJI Mavic 2 pro sensor. A total of 1 906 images with a resolution of 1.5 cm per pixel, using the 1” CMOS multispectral sensor on board have been acquired. The data were collected on November 3 and 4, 2021 in overcast conditions to avoid shadows and a wind speed below 20km/h to ensure the stability of the UAV. The acquisitions were made between 12 pm and 2 pm local time, with a water height of 0.48 m at low tide. The flight altitude was approximately 50 m aboveground. For this first acquisition, a total of 6 targets were distributed in the field. The Metashape targets were printed on conventional paper previously glued on plywood boards. However, due to the size of the study area, it took us half a day to position the targets, convert them into the GNNC (Geodetic Network of New Caledonia) network and retrieve them at the end of the mission. In addition, because of the tide, the recovery of the targets had to be done quickly. Moreover, some targets had been moved by local people. That is why a new system of fixing the targets has been set up (Figure 5). It consists of creating a 50 cm deep hole in the ground, placing a PVC tube in it and driving a stainless-steel rod into it. A metallic support was attached to the rod, on which a Metashape target printed on an alucobond plate of 50 x 50 cm has been fixed. The coordinates of the targets have been observed in static mode for 15 min with a GPS Trimble R8S and repeated 15 days later. A difference in altimetry and planimetry of 7 mm between both campaigns has been observed. This difference is probably due to the position of the GPS on the target center. The position of the 12 targets has been defined taking into account the study of Santos Santana et al. (2021) about the distribution of targets. The distribution of our GCPs is shown in Figure 3. These targets must be preserved for the duration of the project, i.e. 3 years.

**Figure 5.** Photographs of the first target placed in our study area for photogrammetric acquisitions (left : concrete base; right : target on the top of the steel).

**3.2.3 Data acquisition using TLS:** In order to carry out TLS acquisitions in the mangrove, an adequate acquisition protocol must be defined. Indeed, the Trimble X7 scanner (Figure 6) has the particularity of automatically registering point clouds between them in real time. However, depending on the distance between two successive stations and the rate of detected overlap, the registration is done more or less accurately. In addition to the forest scanning, two specific scans are carried: the scan of an individual tree and the scan of pneumatophores. Thus, it is necessary to check that the select density of point clouds is sufficient to visualize perfectly the objects to be studied (pneumatophores, trunks, branches). Therefore, a compromise must be made between scan duration, point density and registration accuracy. The TLS data were collected on March 21, 2022. The first experiment consisted in performing 5 scans respectively spaced from 3 m, 4 m, 5 m and 6 m (Figure 7) in order to investigate the optimal overlap. Also 2 different densities have been tested through different scan durations. It generates different scan durations (8 min and 13 min). The registration reports show errors of 2 to 5 mm for distances of 3 to 8m. Beyond that, the errors are greater than 5 mm, for example up to 1.12 cm for a distance of 17 m.

**Figure 6.** Laser scanning measurements using a TLS (Trimble X7).

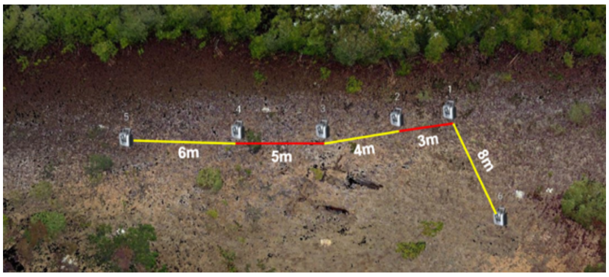


**Figure 7.** Placement of the stations at different distances from each other in order to estimate the optimal distance for a compromise between accurate registration, a short scanning time and a dense point cloud.


**Figure 8.** Point cloud covering some pneumatophores.

It can be concluded that for detecting pneumatophores, it is necessary to define a maximum distance between 2 scans of 8 m with a scan duration of 13 min to ensure sufficient density on the object (Figure 8). The individual trees have been scanned from 4 stations around the tree and with a scan duration of 13 min. The result is presented in the Figure 9. In a future step, the objective will be to determine the structural parameters and the pneumatophores of an individual tree from this kind of data.


**Figure 9.** Point cloud representing an individual tree acquired from TLS.

### 3.3 First step of species classification

A first study was conducted on the classification of mangrove species. To save time, the first tests were conducted on a part of the study area. The first step was to visualize the influence of tree height on species classification. For this, we first created a raster image from the point cloud and then a thresholding in several altimetric classes was performed on CloudCompare (figure 10). Thanks to the thresholding we were able to detect certain zones. For example, the tanne area is perfectly detectable since it is devoid of vegetation, so the altitude is lowest. We also notice in red, in the northwest of the area, large trees corresponding to large *Rhizophora Stylosa*. However, the boundary between medium *Rhizophora* and *Avicennia* is not visible from above. Two reasons might explain this: a) the height of trees is the same or b) medium *Rhizophora* are generally taller than *Avicennia* but because of the slightly downward slope towards the seashore, the difference can not be detected. Point altitude thus seems to be a good criterion for delimiting tannin zones as well as large *Rhizophora* but is not sufficient to distinguish medium *Rhizophora* from *Avicennia*.

In order to automatically delimit tannin zone using the criteria of point altitude, an algorithm has been implemented in Matlab. Firstly, it sorts the set of points along the X-axis. The algorithm then scans the x-axis according to an interval defined by the user. The extreme points ($Y_{min}$ and $Y_{max}$) are recovered in order to delimit the contour of the study area. For each given X interval, if the algorithm detects a difference in altitude (tolerance defined by the user), then a point is created, otherwise, the calculation continues until there is no more point for a given X value. The assessment of the result has been performed by comparing the automatically detected areas with the ground truth. The blue line (automatically created) follows roughly the brown line (land), i.e. it looks coherent. Thus, the use of point altitude seems to give promising results for the automatic delimitation of at least tannin areas. Unfortunately, the limit of medium *Rhizophora* and *Avicennia* (represented in orange line) is not detected by the algorithm. Figure 10 shows the result of the algorithm (blue lines) and data acquired by conventional measurements using a GPS (lines with different colors according to the species).

The direct use of a point cloud requires a lot of memory and the calculations can be relatively time consuming. That's why in order to improve the processing chain, a raster image produced from the point cloud and containing the altimetric information will be used in a future experimentation, as suggested by Kamal et al., 2015.

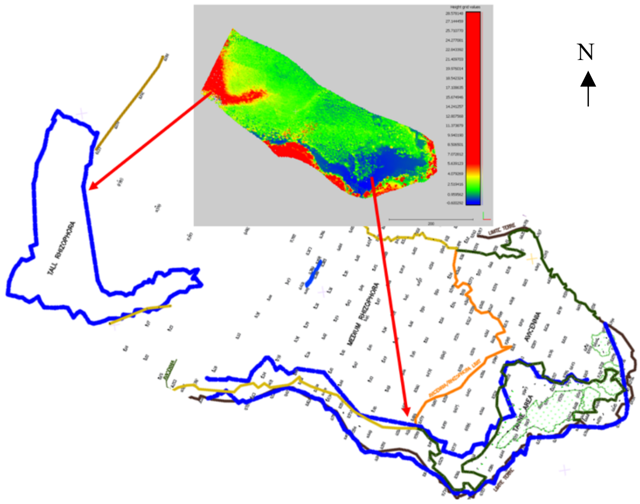


**Figure 10.** Comparison of the results obtained by the classification algorithm implemented in the study (blue line) and the field acquisitions using GPS (brown line). The orange line represents the limit of medium *Rhizophora* and *Avicennia*. The color panel represents an altitude gradient. Red is the higher altitude and blue is the lower altitude.

## 4. CONCLUSION AND FURTHER WORKS

The purpose of this paper was to present on the one hand the research project and on the other hand the first species classification results. The long term objective of the project is to understand and monitor the evolution of mangrove forests using remote sensing techniques. The use of aerial images, TLS, ALS or a combination of them, depends on the characteristics to analyse. The first step of this project was to set up an acquisition protocol for both photogrammetric and laserscanning data with the aim to detect characteristics among mangrove species, structural parameters of trees, pneumatophores and LAI.

Acquisitions have been made using UAV and TLS. The UAV acquisitions were useful to determine limits of the different species while the TLS acquisitions allow the study of individual elements (pneumatophores, isolated trees). The first test carried out concerned the classification of mangrove species using the point altitudes. The results showed that this criterion is promising for determining the limit of the tannin zone and probably also that of the large *Rhizophora*. But it was not sufficient to differentiate the medium *Rhizophora* from the *Avicennia.* In a future work, additionnal data will be used to improve the results and extend the detection to other characteristics, like laser intensity, thermal or infrared information.

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