CHAPTER 5

The Role of GIS and LIDAR as Tools for Sustainable Forest Management

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Abstract: Regarding activities related to sustainable forests management, the spatial location of information is a very important factor, which requires tools capable of acquiring this data and handling them in a georeferenced format. For this reason, forest management has rapidly incorporated geospatial tools offered by new information technologies. Two important technologies used are Geographical Information Systems (GIS) and the remote sensing technology known as LIDAR (Light Detection and Ranging).Forestry applications of these technologies can be grouped into two broad categories: (i) Inventory and monitoring of natural resources; and (ii) Analysis and modeling of resources to facilitate sustainable planning and management. The first category is designed to measure the surface area, quantity, composition and condition of forest and natural resources of a management area. Thus, foresters use the LIDAR technology for acquiring digital information on the structure of the forest and the terrain; this information, properly processed with a GIS, helps analysts in assessing the health of the forest, calculating and classifying forest biomass, classifying land, or identifying soil drainage patterns, among other things. In the second category, once the above mentioned information has been mapped in a GIS environment, it is accessible to managers and researchers who can analyze and create models that optimize the decision-making on the resources under management, facilitating and optimizing forest planning. Therefore, wood felling can be scheduled in a sustainable way, as well as the design of firefighting infrastructures or the optimization of any other decisions related to use of resources or the protection of wildlife. This chapter aims to make the reader familiar with some variables of sustainable forest management, and with their integration into a GIS environment, as well as to introduce the basics of LIDAR technology and its powerful capabilities to acquire useful information for forest managers and planners.

Keywords: Digital Surface Models (DSM), Forest biomass appraisal, Forest management and planning, Geographical Information Systems (GIS), Geospatial tools, Light Detection and Ranging (LIDAR), LAS file.

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INTRODUCTION

Worldwide, forests are a source of products, water, biodiversity, ecological balance and human health plus life quality. Forest conservation is a major issue of environmental world policies; woodlands need protection against overexploitation, exposure to pollution, fire hazards, and deforestation intended for other land uses.

A milestone with regard to forest conservation and protection was the Rio de Janeiro United Nations Conference on Environment and Development (UNCED) celebrated in the year 1992, also known as the Earth Summit. The importance of forests for the environment and for a balanced economic development of humanity was there set up, thus concluding that the sustainable use of forests should be considered as a basic element of Nations' sustainable developments [1].

In 1993 at the second Ministerial Conference on the Protection of Forests in Europe (MCPFE) held in Helsinki, Resolution H1 on the "General Guidelines for the Sustainable Management of Forests in Europe" provided the following definition regarding a Sustainable Forest Management (SFM):

> […], "sustainable management" means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems [2].

Addressing forest problems throughout the World has produced several forest management certification schemes, at regional as well as global levels; all of these schemes are based on certain principles or criteria which have been developed through indicators. An example of such a criterion set adopted by some certification schemes, is the pan-European criteria published for SFM at the Third MCPFE (Lisbon 1998), adopted following the technical meetings held in Geneva (1994) and Antalya (1995) [2]:

1. Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles.
2. Maintenance of forest ecosystems' health and vitality.
3. Maintenance and encouragement of productive functions of forests (wood and non-wood).

4. Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems.
5. Maintenance, conservation and appropriate enhancement of protective functions in forest management (notably soil and water).
6. Maintenance of other socio-economic functions and conditions.

In forestry properties, the basic tool to achieve healthy and useful forests, thereby to comply with all of the SFM criteria and indicators, encompasses the Management Plan (MP).

Management Plans

The MP is a document or a set of documents that should contain useful forest information for decision making and development of an action plan (see *e.g.* [3].).

Some MP items as directly related to the topic of this chapter will further be described briefly.

General Information Regarding the Managed Area

- Spotting of protected habitats and protected species: they need to be localized on a map, as well as the buffer areas that may suffer exploitation restrictions.
- Landform analysis: steepness, microclimatic conditions, view-points, view-sheds and other factors related to the relief set up of management constraints.
- Land cover: forests are divided into management areas depending on vegetation type, tree species, site quality, tree and shrubs densities, *etc*.
- Infrastructures: roads, tracks, footpaths, firebreaks, watering points, fences, and any other infrastructure need to be located, whenever useful for forestry management practices.

Forestry Resources Information

- Existing resources such as wood, fuelwood, biomass, cork, pine cones, oak acorns, mushrooms, grazing grass and shrubs, herbs or any other actual or potential productions.
- Tree density: one of the main management variables; density and age define the clearings and regeneration fellings.
- Canopy cover and basal area: along with tree density these variables allow to evaluate optimal land productivity uses.
- Wood volumes and growth: calculated from tree height and diameter, allow to compute estimates on wood yield.
- Biomass volumes and growth: modeled from several tree variables, allow to obtain estimates on biomass yield.
- Age structure of the forest: within each management area and in the whole of the

forest managed, age structure will condition the silvicultural and management systems.

- Forest fire risk assessment, depends on terrain and meteorological variables as well as on vegetation and stocked fuel conditions.

Action Plans for SFM

- Calculating the sustainable yield of wood, biomass or any other forest products.
- Localizing and quantifying the log fellings planned on a yearly basis during 5 up to 10 years. All restrictions regarding biodiversity, landscape, soil erosion or any other limitation will be integrated into this planning, in order to determine felling areas as well as felling techniques.
- Infrastructure development for fire protection and recreational use.
- Infrastructure development for resource exploitation.
- Localizing and quantifying any other actions for forest improvement, wildlife protection, *etc*.

TOOLS FOR INVENTORY AND MANAGEMENT PLANS

As has already been noted, resources information entails a basic step to manage resources in a sustainable way. Information is obtained by means of forest inventories, based on forest sampling plot measurements together with statistical analysis of the sampled data.

In order to measure sampling plots, a team of 2 to 4 persons must localize the plot's center and identify the trees inside of the plot, measure the trees and count them. Staff may also mark down any other relevant information on the ecological features of the sampled area.

Plot measurements are time consuming and costly, so the number of measured plots must be limited to that strictly necessary. Depending on the variability of the forest characteristics, the number of plots may vary from about one plot per hectare to one plot every 25 hectares.

Ever since invented, remote sensing has broadly been applied in order to reduce plot samplings. Satellite or airborne multispectral images (MS images) are very useful to identify tree species, canopy cover, vegetation health, terrain elevation and other useful data (see *e.g*. [4, 5].). Nevertheless, these images have low performance in providing most of the quantitative information concerning forests (*e.g*. [6].), as listed before.

The LIDAR (Light Detection and Ranging) technology has been a revolutionary tool to obtain a huge amount of terrain data. It does not only obtain terrain elevations but in addition also gives the terrain surfaces covered by each vegetation layer (grass, shrubs and trees). Table **1** presents the referred management variables as well as the tools needed or useful to obtain them.

Table 1. Potential application of management tools to evaluate variables of forestry management plans.

Variable	On-site plots	MS Images	LIDAR	GIS Analysis
Protected areas		A		N
Landform analysis			A	N
Landcover	A	A	C	P
Infrastructures		A		N
Existing resources identification	N			
Tree density	N	A	B	P
Canopy cover-basal area	N	A	B	P
Wood volumes – growth	N		B	P
Biomass volumes and growth	N		B	P
Age structure	N		A	P
Fire risk assessment	N	C	A	P
Sustainable yield	N		A	P
Felling areas				N
Infrastructure planning				N

A: aid, very helpful; C: complementary aid; N: necessary; B: alternative to a needed tool; P: processed from LIDAR data or image processing.

As can be noted from Table **1** the LIDAR data should be matched to some reference plot data, in order to calibrate the system and so to minimize the errors. Anyway, the applicability of the LIDAR technology may drastically reduce the number of sampling plots, as long as the LIDAR data are available at an affordable cost.

This chapter aims to present the basics of LIDAR technology as well as its actual applications, combined with GIS, for the improvement of the quality and quantity of data used in forest management and planning. These improvements may also cause a significative cost reduction on data acquisition, which may lead to a better monitoring of all kind of forests.

THE LIDAR TECHNOLOGY

The LIDAR technology is an active detection technique which uses the same principle as the RADAR technology, yet instead of using radio waves uses a laser beam. While the RADAR uses radio waves to determine an object's distance by measuring the time delay between a pulse transmission and the detection of the reflected signal, the LIDAR makes use of much shorter wavelengths of the electromagnetic spectrum.

The wavelength used by the laser of the LIDAR systems may vary between near infrared (NIR), ultraviolet (UV) and visible (VIS), according to the measurement's objective. While to measure short and medium distances (topographic works) a wavelength of 1064 nm (NIR) is utilized, for bathymetric measurements the wavelength must be adjusted to 532 nm (green) [7], as displayed in Fig. (**1**).

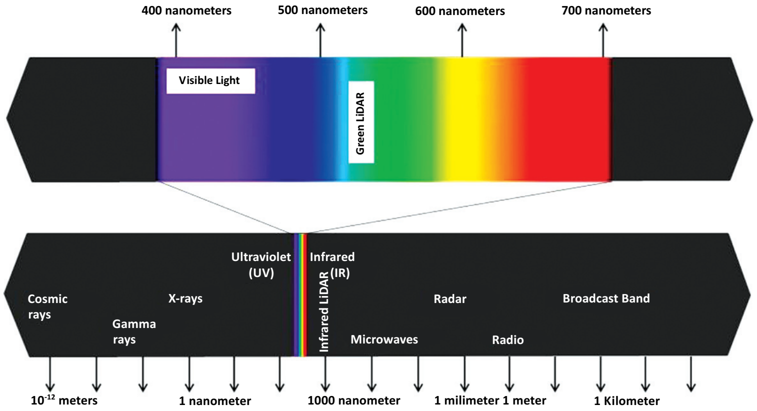

Fig. (1). Electromagnetic Spectrum indicating the most usual Wavelengths of the LIDAR Systems.

Therefore an object's distance is determined by measuring the time delay between emission of a light pulse and detection of the pulse reflected back from the object (Fig. **2**), taking into account that the laser light pulse travels at the speed of light.

With the intention of mapping large areas, the possibility exists to mount the LIDAR system on an aerial platform (airplane, helicopter or drone), from which to send the light pulse to the Earth's surface; some of these pulses bounce back to the LIDAR sensor. The time taken by the laser beam to reach the Earth's surface and bounce back to the sensor in the air transport is used to estimate the Earth surface element's distance.

The LIDAR scanner is composed not only of the transmission and reception laser, in addition it also presents a differential satellite global positioning system (DGPS), which is applied to determine the platform's location, together with an inertial measurement unit (IMU) which enables to determine the platform's angle (pitch, roll, yaw) (Fig. **3**). The information provided by the three systems, once integrated mathematically, provides a point cloud which records for each item the horizontal coordinates (x,y) and the elevation (z).

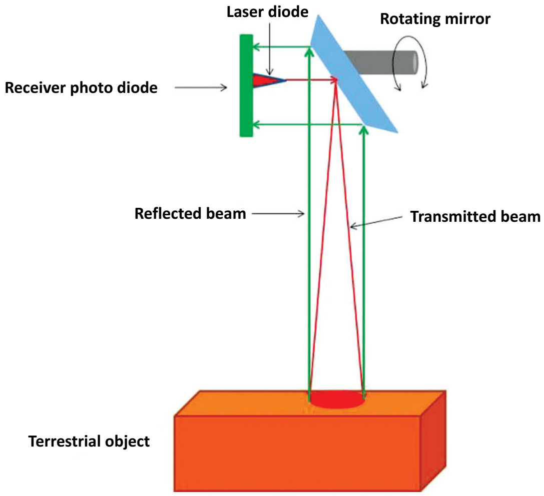

Fig. (2). Diagram of a LIDAR scanner and its working principle.

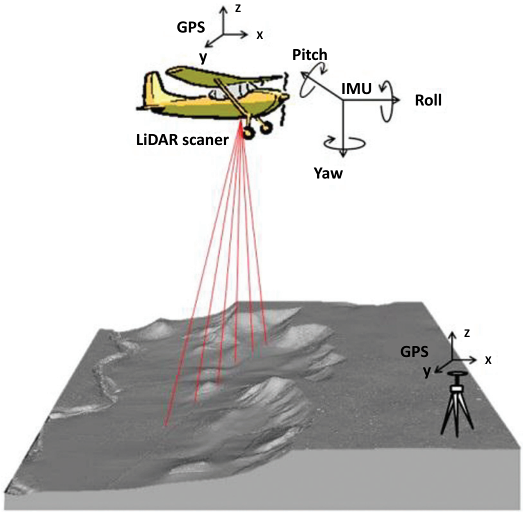

Fig. (3). Components of a LIDAR system.

This type of technology allows to directly measure three-dimensional structures and terrain surfaces. Depending on the method used to capture data, extremely dense point clouds can be obtained compared to other capture methods (up to five points per square meter). The result of opting for such a high resolution technology entails a higher measurement precision of the terrain elevations and the ground objects' heights. This feature is one of the foremost advantages of the LIDAR technology in comparison to other conventional optical instruments, such as digital cameras. On this respect one of the first things to draw the attention to this technology encompasses the effective altimetry accuracy which can be retrieved. Although the exact precision remains unknown, studies that have so far been conducted agree that the altimetry accuracy achieved is higher than that obtained with planimetry, given that for extended areas the mean square error of the planimetric coordinates [x,y] is estimated to amount to about 15 cm, while for the "z" coordinate errors below 8 cm can be attained [8]. This accuracy can also be achieved through photogrammetry, although this option is more expensive and requires much more time handling and processing data.

A laser pulse produced by a LIDAR system embodies a known finite diameter, therefore it could be possible that only part of the laser's diameter was reflected on a certain object, while the rest of the pulse would continue to travel until reflecting on another object, thus the original pulse would have produced a second reflection. Each pulse can in principle generate several reflections or returns as can be seen in Fig. (**4**).

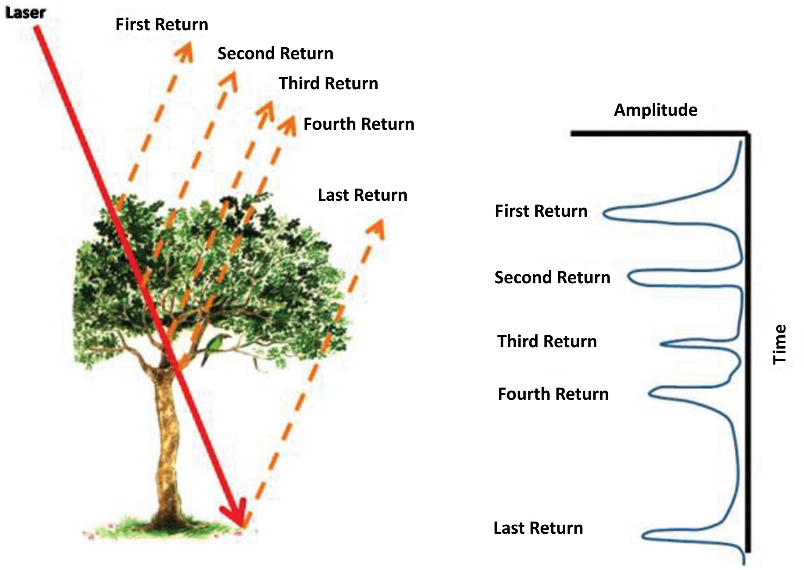

Fig. (4). Various reflections generated by a laser pulse emitted by the LIDAR System.

Initially, LIDAR systems were only capable of recognizing a single return, nonetheless currently they can measure several returns per pulse (from 3 to 5) [9]. These multiple returns can be used to study and to analyze the information about the objects on the Earth's surface. The signal of the first pulse allows describing the surface or upper part of an object, while the signal of the last eco is typically used to measure the soil surface.

Obviously with more returns per pulse registered the more accurate will be the information retrieved from the scanned surface, but the LIDAR dataset will tend to be very large, simply owing to the large number of pulses emitted by the laser scanner. Therefore most LIDAR systems have been designed to record up to five returns per pulse, given that in practice it has been established that the fourth and fifth pulse rarely occur.

The data quality and quantity obtained through a LIDAR flight depend directly on some parameters of the laser scanner and on the flight's configuration, given that these determine the point density captured by the LIDAR system. The flight configuration parameters with a higher influence on quality are depicted in Fig. (**5**) and listed below [10]:

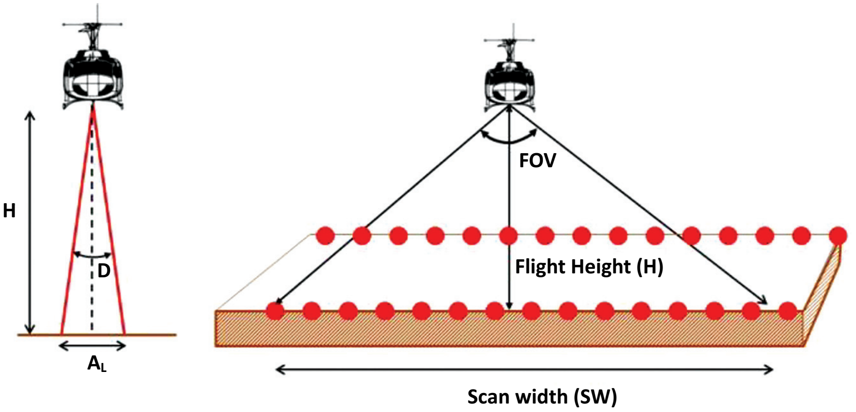

Fig. (5). Main flight parameters which sustain an influence on the LIDAR data quality obtained.

<u>*Pulse Frequency (F):*</u> Corresponds to the number of laser pulses that the sensor is capable of emitting per second, usually in the range between 200,000 to 400,000 pulses per second (200 to 400 KHz).

<u>*Scanning Frequency (fc):*</u> Number of scans per second or scanned lines per second, usually 25 to 90 Hz.

Field of View (FOV): Maximum angle at which the laser beam is emitted perpendicular to the flight direction. Generally the low field of view angles are more interesting, since usually with smaller FOV a higher product quality is obtained, since for example very large angles increase the footprint's size with respect to the size of the footprint in the nadir.

Flight Height (H): Corresponds to the scanning's executed height. Depends on the laser transmission's power and also on the mobile platform operated.

Maximum Scan Width (SW): Maximum scan width transversal to the flight direction, depends on the FOV and the flight height.

Divergence of the Laser Beam (D): Aperture angle of the laser beam.

Laser Footprint (Al): Illuminated Surface by a laser beam. Depends on the beam's divergence and the flight height.

Return Density per Surface Unit: Corresponds to the number of returns per surface unit.

Considering forest areas, the first pulse will impact on the top canopy allowing to characterize forest variables related to mass height or the canopy cover fraction. Part of the pulse can generate second, third or further rebounds while reflected on other plant parts such as leaves, branches or trunks, which allow to study or characterize forest variables, such as the canopy volume, the number of trees per hectare or other density variables. The last rebound registered matches usually the part of the laser beam reflected on bare soil, allowing to create topographic maps or terrain elevation models.

Recently, the LIDAR systems used to measure forest variables have evolved, allowing to be greatly improved [11, 12] in this manner they have incorporated laser beams of a greater diameter or footprint (diameters of 5m up to 25m) being able to receive and process the complete pulse wave, instead of only storing pulse returns. These improvements consent to attain a better characterization of the intermediate parts of the canopy and therefore of the forest's vertical structure (Fig. **6**).

LIDAR systems, in addition to recording the time lag between the pulse emission and reception, are also able to store information about each bounce's intensity or energy amount reflected, *i.e.* the laser beam's return force after being reflected by an object. Consequently, high reflectivity objects as could be snow or metal roofs evidence high intensity or energy returns, while objects of a low reflectivity as for instance roads return low energy or low signal strength pulses. Water bodies absorb most of the laser beam energy and no rebounds are generated, except if adequate wavelengths are radiated (near to the green region of the spectrum).

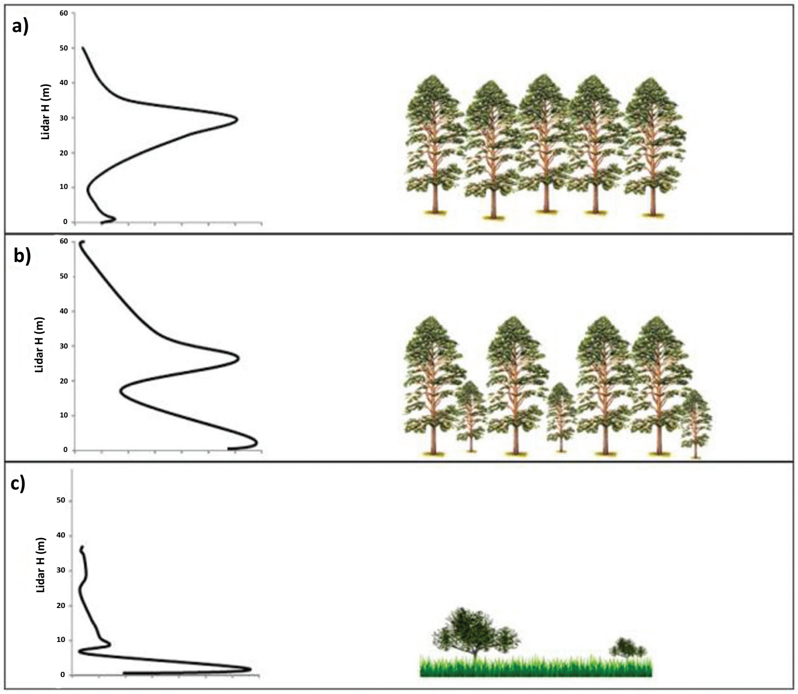

Fig. (6). Laser beam response to different mass structures: (**a**) a regular mass of a single layer (**b**) a mass with two height layers (**c**) absence of trees, bare soil with a bit of scrubland.

This rebound intensity information can be used to generate an image; usually an 8 bit color depth (256 colors) which applied to a grayscale palette allows to visualize point clouds similar to those of a panchromatic orthophotography (Fig. **7**). This orthophotograph once properly treated with a geographic information system, allows to generate a raster layer or orthophotograph of a certain precision, each pixel's digital value containing the average of all the signal rebounded intensities falling within a same pixel.

However, it should be noted that the digital value stored within a pixel corresponds to the object's reflectivity according to the laser wavelength applied being the derived intensity data set not standardized, therefore its use is limited to create orthophotographic images which prevent to retrieve any other information. An interesting advantage given that the LIDAR system uses an active sensor, image intensities do not depend on the prevailing light conditions, allowing to capture data under cloudy conditions and even nocturnally.

Fig. (7). Rebound intensity image of the LIDAR system.

The information gathered by the LIDAR sensor is stored in a file type “Laser file format Exchange activities” also known as LAS file, whose specifications have been developed by the American “Society for Photogrammetry & Remote Sensing”. The LAS file is encoded in a public exchange format comprising three-dimensional point type data, each point storing as minimum: the x and y coordinates together with the registered height, the rebound intensity, the emitted pulse number, the reflected pulse number, last, the pulse emission angle.

INFORMATION PROVIDED BY LIDAR

The LIDAR technology presents many advantages compared to the other traditional cartographic techniques, such as photogrammetry. It possesses the ability to simultaneously record information on the structure of the vegetation cover and on the soil surface that exists underneath of the tree canopy, an unthinkable question attained by using the traditional techniques of photo-interpretation. This sampling accuracy increase of the soil surface substantially allows to improve the ground topographic analysis achieving a better understanding of the geographic features.

In this manner the first product that can be obtained by the LIDAR information consists of a digital terrain model (DTM), which simply can be defined as a numeric data structure representing the spatial distribution of the variable ground height. Generation is achieved using the rebounds reflected on the bare ground, regardless of whether they are the first, second or third rebound.

The next information derived from the LIDAR point data clouds are the digital surface models (DSM) which correspond to digital terrain models that include the elevations of existing objects on the Earth's surface, such as trees, buildings or the bare soil with no previous coverage [13]. This surface model is of particular interest to the forestry sector, as it offers a clear view of the highest canopy surface of wooded areas. This model is generated, logically from the first rebound of all the pulses [14], (Fig. **8**).

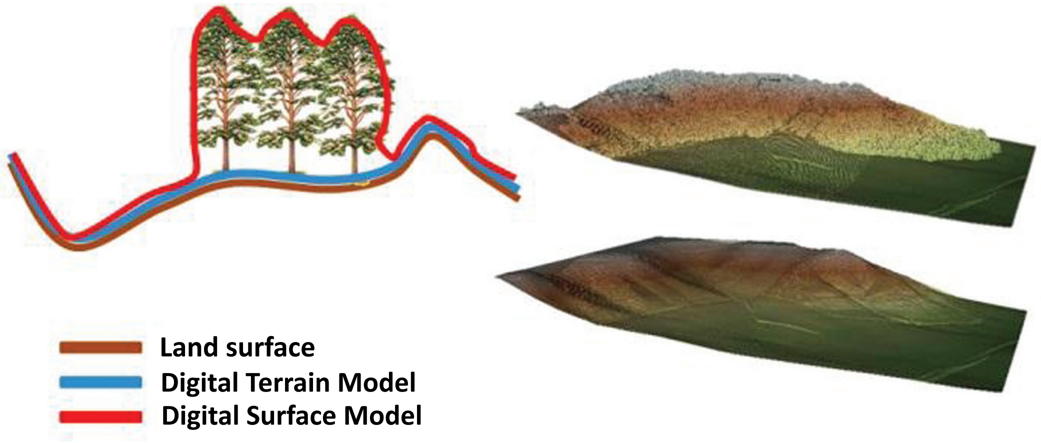

Fig. (8). Digital Terrain (DTM) and Surface (DSM) Models: DSM (red line and upper 3-D image) includes canopy cover, whereas DTM (blue line and lower 3-D image) represents the bare ground landforms.

In contrast to the two previous models a third product of great forestry interest is obtained consisting of the vegetation’s digital model containing the canopy heights read by the LIDAR scanner (Fig. **9**).

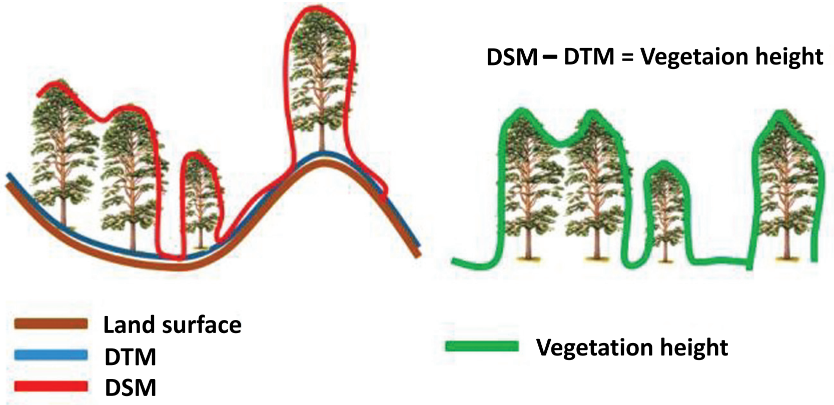

Fig. (9). Standardization of the Vegetation height recorded by the LIDAR scanner.

Handling LIDAR data applied to forest inventories can potentially provide forest variables at an individual tree level, allowing to obtain a broader picture of the forest's real structure. These forest mass variables usually are: height, canopy fraction and tree profiles. These attributes can be used to derive other forestry measures such as the bi-symmetrical area and wood volume, as well as the biomass amount for energy production and the analysis of forestland carbon capture.

THE FORESTRY INVENTORY WITH LIDAR

Undoubtedly forestry is one of the fields in which the LIDAR technology has exhibited its highest potential, thanks to this system's ability to generate dense three-dimensional point clouds. LIDAR data provides horizontal and vertical information with a high spatial resolution and accuracy, with forest attributes impossible to be obtained by any other remote means [15, 16]. Numerous authors have presented results demonstrating the LIDAR system's capability of measuring dasometric forest mass variables and individual trees dendrometric measurements [17 - 24].

Giving the main points on the forest variables obtainable or directly derived from the LIDAR data would be: canopy height, underlying canopy topography, aboveground biomass, basimetric area, average trunk diameter, treetop volume or vertical distribution of the vegetation [25 - 34].

Prior to obtaining any forest variables resulting from a LIDAR flight, a pre-processing of LAS files is always needed, which usually consists of a point cloud filtering (identification of bare soil returns and identification of returns produced by objects on the ground), the MDE generation and the standardization of each return's height with respect to the ground (or creation of the MDV), followed by a statistical analysis of the rebounds above a determined height (metrics of the LAS file) (Table **2**).

Table 2. Statistical Variables with forestry interest derived from a LAS file (flight metrics).

Statistical Variables derived from the laser return above a certain height	Forestry Utility
Percentage of first returns above X meters	Canopy cover (%)
Minimum Elevation	Lowest canopy height
Maximum Elevation	Highest canopy height
Mean Elevation	Average Canopy Height
Elevation mode	Canopy Height Mode
Elevation Standard deviation	Forest regression models

(Table 2) contd.....

Statistical Variables derived from the laser return above a certain height	**Forestry Utility**
Elevation Variance	Forest regression models
Elevation Coefficient of variation	Forest regression models
Elevation Coefficient of skewness	Forest regression models
Elevation Interquartile range	Forest regression models
Elevation Coefficient of Kurtosis	Forest regression models
Elevation Average Absolute Deviation	Forest regression models
Elevation Percentile 1 to 99	Forest regression models

A significant number of the main forestry attributes can be directly obtained from the (X, Y, Z) data provided by the LIDAR system LAS files; namely some of these attributes could be: Individual tree height, Average canopy height, Dominant height, Canopy cover, Number of trees, Crown size, Height to live crown, Crown volume.

Other variables must be obtained indirectly by establishing statistical models through empirical relationships, namely *e.g.* Wood volume, Biomass, CO_2 stocked in biomass, Quadratic mean diameter, Basal area, Leaf area index, Crown density.

As already mentioned above the forest variable estimates derived from LIDAR data can be processed resorting to either of two approaches, depending on the rebound densities obtained in LIDAR flights.

The first approach involves evaluating forestry variables at the individual tree level which necessitates of flights capable of obtaining high point or rebound densities comprising 5 to 10 rebounds per m2 [35]. The second approach corresponds to estimating forestry variables for an entire area or woodland, be it a piece of inventory, a stand or a complete scrubland; corresponding usually to flights covering low point densities containing 0.5 to 4 rebounds per m^2 [36, 38].

The most pronounced difference between these two approaches encompasses that the first method or tree method is based on the detection and delineation of individual trees to subsequently apply allometric equations at the individual level; in contrast the second method or mass method uses directly the returns reported by the LIDAR sensor onto the work surface (plot, stand or scrubland) in order to establish statistical relationships allowing to estimate the forest variables of interest.

The mass method attempts to reflect both the vertical and the horizontal space organization of the forestry mass components. This type of inventory is possible owing to the LIDAR point cloud describing in detail and in a continuous manner the vegetation structure as can be appreciated in Fig. (**10**).

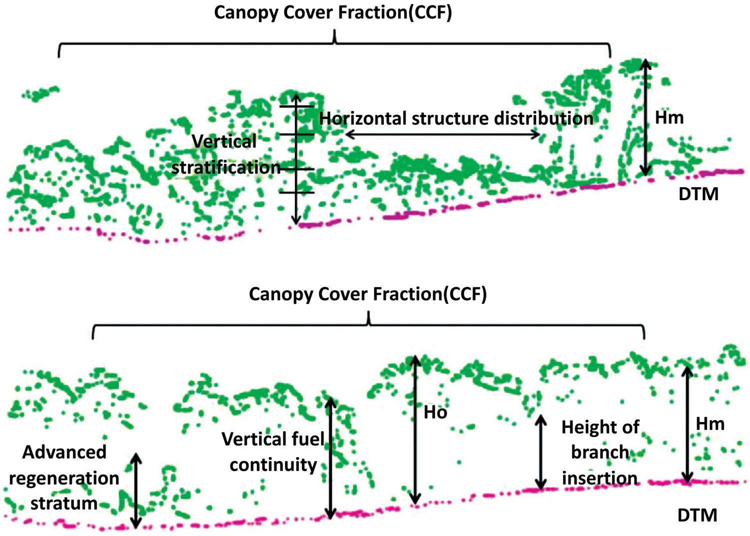

Fig. (10). Possible description of the horizontal and vertical mass structure.

In this inventory type the objective is based on knowing along the entire scrubland surface the following forestry variables: basimetric area, dominant height and wood volume among other things.

In general the LIDAR inventories carried out by the mass method are considered as double sampling inventories. The objective of this inventory method consists in estimating determined forest variables, such as the basimetric area whose measurement results costly, by means of exploiting its relationship with other auxiliary variables easier and more economic to measure; in this case, the basimetric area can be estimated using percentiles, the standard deviation of the point cloud's height distribution or the rebound percentage above a certain height (Fig. **11** and **12**).

Numerous studies seem to have obtained good results with respect to various forestry variables, determining their value with an acceptable accuracy, for example, Means *et al*. [19] used the height distribution percentiles and the canopy cover fraction to estimate the mean mass height, wood volume and basimetric area of a Pseudotsuga douglasii forest, with tree heights ranging between 7 to 52 m, obtaining models with coefficients of determination (R^2) of 0.93 and 0.97 and 0.95 respectively for the average height, the timber volume and basimetric area.

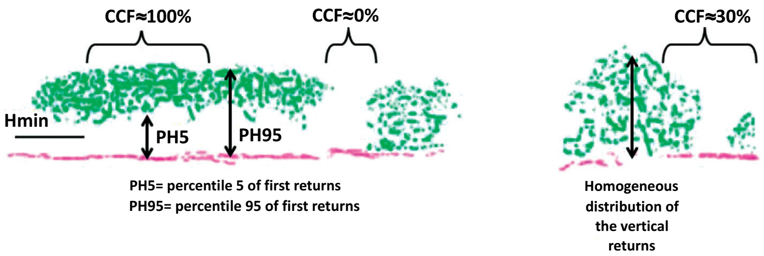

Fig. (11). LIDAR rebound distribution with respect to the vegetation and its relationship with canopy cover fraction (CCF).

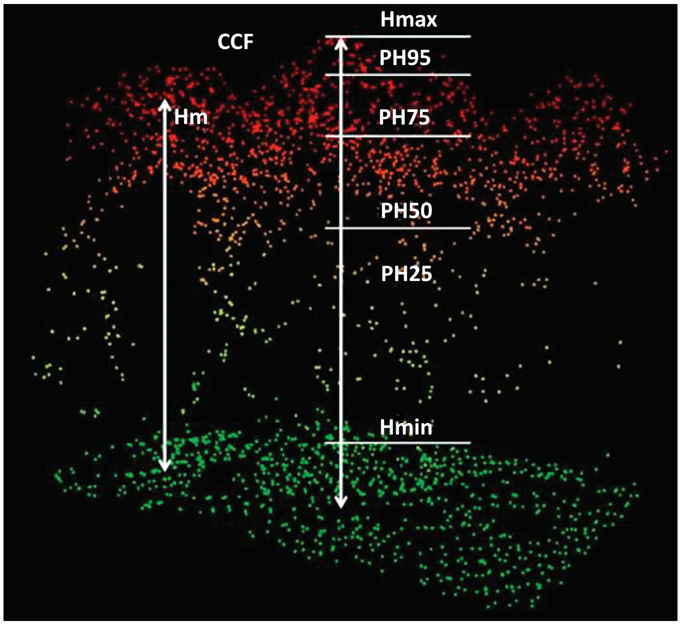

Fig. (12). Relationship between the first rebound percentiles with the canopy cover fraction (CCF) and the mass height.

In Spain, García *et al.* [39] applied this methodology to conduct a forest inventory, attaining equations of total volume, aboveground total biomass, basimetric area and trees per hectare with R^2 values of 0.90, 0.89, 0.89 and 0.80, respectively.

As has already been indicated in the introduction, traditional forest inventories determine the object forestry variables by sampling a small percentage of the surface (sampling plots) to subsequently extrapolate the results to the entire area, by means of other auxiliary variables. The LIDAR inventories require two sampling phases: a first phase carried out on ground which measures or estimates the variable to be modeled in a representative area sample and a second phase which measures the auxiliary variables or LIDAR data, to subsequently establish the correlations between the measurements and the LIDAR data through regression models (Fig. **13**).

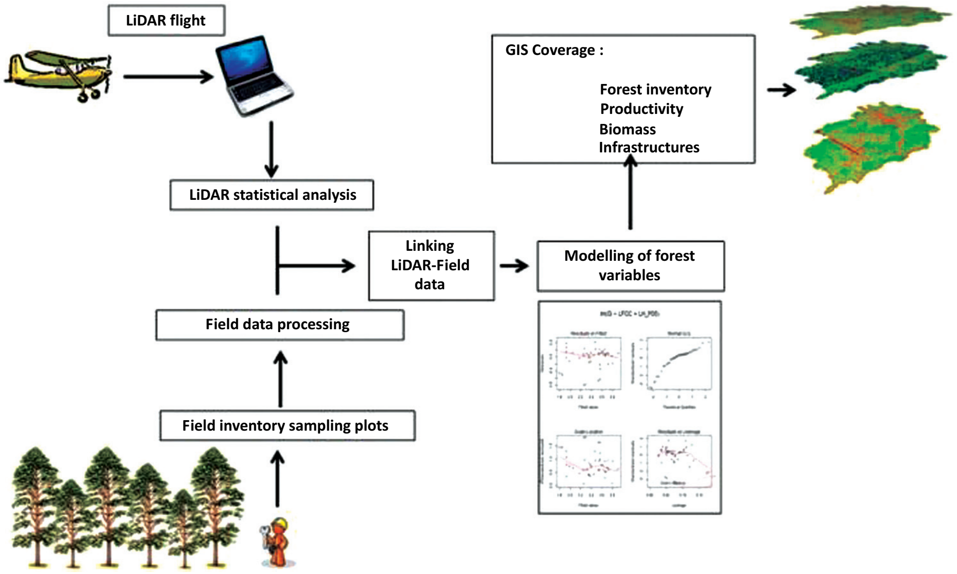

Fig. (13). General workflow of a forestry inventory using LIDAR.

In this manner a traditional forest inventory will have an associated error derived from the sampling fraction, whereas a LIDAR inventory will lack a sampling error as variables are measured throughout the entire mass surface, not being restricted to a fraction. However, the LIDAR inventory is not devoid of errors, since the data's extrapolation is associated to the goodness of fit of the regression models.

Thus, inventories by traditional plot samplings offer good estimates over large management units or strata yet bad estimates in smaller units (inventory unit or stand), on the other hand, LIDAR inventories allow to substantially improve the error estimation of forest variables in smaller management units, making it easier to improve the planning actions at a stand scale and to apply more competently flexible management methods that respond much better to the multifunctional demands that society is requiring out of woodlands.

The main differences between a LIDAR inventory and a classic inventory by sampling can be observed in Table **3**:

Table 3. Main differences between forestry inventories with LIDAR and a classical inventory by sampling.

Characteristic	LIDAR	By sampling
Information volume	Up to 40.000 vegetation height figures per ha	No more than 10 height and diameter figures per ha
Sampling Fraction	100%	Not more than 4%
Errors	Depend only on the quality of the regression models (plus possible instrumental errors).	Depend on the sampling intensity (number of plots) and on the quality of the regression models (plus possible instrumental errors).
Results	Provides details at a local scale and of the entire mass. Problems to distinguish species and diametric classes.	Provides robust data for complete management units, not at a local scale (stands or inventory units. Possibility to distinguish species and diametric classes.
Costs	High fixed cost (flight and processing), but covering extensive surfaces low cost per surface unit (possible multi-functionality of the LIDAR data for large areas).	Low fixed cost, mainly variable cost; with larger surfaces higher costs. In general, highcost per surfaceunit.

THE LIDAR DATA SOURCES

This section wants to convey that in addition to the LIDAR data obtained from a planned flight and adjusted to the work's objectives, currently a series of public access Internet data sets are available, which may be useful with respect to some works. It must be borne in mind that the data set obtained by a planned flight tends to present a much higher quality (usually) compared to the free access data, given that the point densities obtained by the latter tend to be low and do not reach the minimum required for a forest inventory (over 0.8 points/m^2 respective to mass methods and 1.2 points/m^2 for individual trees). Nonetheless, these freely available data sets comprise a very good quality in order to obtain useful information suited for other aspects of forestry planning such as digital terrain models or forestry infrastructure maps.

The online access to the public LIDAR data varies significantly among the different spatial data infrastructures (SDIs); nevertheless most SDIs possess an interactive system which allows to select data from a particular area.

Within the European Union, notably owing to the community 2007/2/EC directive to establish an Infrastructure for Spatial Information in the European Community

(INSPIRE), member States have carried out LIDAR flights over their territories, aiming to obtain high precision terrain digital models. Availability of the raw flight data (LAS data) is uneven among the different countries, given that each country has applied their own criteria regarding quality and geoportal features.

The United States is the country which produces and facilitates most of the LIDAR data; several sites offer free access data, even though all the information is recollected in the "National LIDAR Dataset" project available through the public site of the United States Interagency Elevation Inventory (USIEI).

At a global level two very interesting initiatives can be cited which aim to create a social network to share LIDAR data: i) Open Topography, depending on the University of California; ii) online-LIDAR community managed by the company Dielmo.

When the public data does not adapt to the different objectives set out by the work to be carried out, a specialized company running a LIDAR flight specific to the work area of interest should be hired. Prior to its execution the planning of the flight should be undertaken, taking into account the various flight parameters which ensure that the data captured is sufficient in quantity and quality to generate the required models. The LIDAR flight parameters which mostly influence on the obtained data quality include: the pulse frequency, the scan frequency, the scanner's field of vision, the flight height, the flight speed and the laser's footprint, given that all these parameters affect the retrieved resolution or point density per surface.

THE SOFTWARE FOR LIDAR DATA TREATMENT AND INTEGRATION

It should be taken into account that the LIDAR data treatment and management applications are continuously being renewed, particularly when such a novel and innovative subject as the LIDAR systems are considered. Therefore, Table **4** intends to give a general outline of the most featured and commercially available software packages.

Table 4. Some examples of software for LIDAR data treatment.

SOFTWARE NAME	Creator	Processing	Source	Observations
TerraScan	Terra Solid	Whole	C	
BCAL LIDAR Tools	Boise State University	Standard	O	Complement to the remote sensing ENVI software package

(Table 4) contd.....

SOFTWARE NAME	Creator	Processing	Source	Observations
FugroViewer	Fugro	Standard	O	Displays other vector/raster data
Fusion/LDV	USDA	Standard	O	High quality for DTM and DSM
LASTOOLS	Rapidlasso GmbH	Standard	C	
ArcGis	ESRI	Standard	C	
Global Mapper – LIDAR Module	Blue Marble Geographics	Standard	C	

Whole processing: all processing, including calibration of the LIDAR sensors and data quality control; Standard processing: classify, convert, filter and transform the point clouds to a raster image; C: Commercial; O: Open source, free software.

CONCLUSIONS

Decision taking processes in forest management and planning need information on a wide range of tree and vegetation variables, infrastructure, landforms, *etc*. All this information is nowadays managed by means of GIS.

Forest inventory variables can be obtained on-site by measuring forest variables in sampling plots. It is a costly and time consuming work; some forest areas may be very difficult to access. As forests grow and change, inventories need to be updated every 5 to 10 years.

Multispectral remote sensing images have been used on forest management and planning ever since they were available. These images are very helpful on identifying different land cover areas, locating infrastructures, *etc*. GIS platforms allow viewing and processing (manually or automatically these images). However accurate quantitative information on forest mensuration is not provided by remote sensing images.

LIDAR technology uses the reflection of a laser beam signal, broadcasted from an aircraft, to scan a 3-D model of the terrain, vegetation or any other objects covering the terrain surface.

As trees and vegetation in general are not opaque solids, the data obtained need to be classified, filtered and converted by means of algorithms implemented through the adequate software; most GIS platforms have tools developed for this purpose.

The processed LIDAR data provides directly forest variables such as Individual tree height, Average canopy height, Dominant height, Canopy cover, Number of trees, Crown size, Height to live crown, Crown volume. Other volumetric variables like wood or biomass volumes can be inferred from regression models based on data from on-site plot samplings.

LIDAR data must be sufficient in quantity and quality to generate the surface models; the flight parameters will prompt the utility of data for forest inventory.

LIDAR technology decreases dramatically the cost of forest inventories for broad areas of managed forests. It does not mean the disappearance of fieldwork but its reduction, especially for inventory updates, when a basic on-site sampling has been carried out previously.

High-performance LIDAR technology involves bulky, heavy components that usually require manned aerial platforms to operate. However, the development of Micro-Electro Mechanical Systems (MEMS) has made it possible to reduce and lighten LiDAR systems, facilitating their integration into micro unmanned aerial vehicles (UAVs or drones), where they can be combined with other remote sensing devices such as infrared or visible spectrum cameras. These systems have very low flight height, so they can provide greater precision than manned platforms, but their efficiency will be much lower because they have a narrower scan width. They can be very useful for providing detailed, low-cost information on the inspection of logging or any other forestry work at the local level.

LIDAR information implemented on a GIS platform can be considered a revolution in forest management and planning; this technology will allow proper sustainable management of natural areas or of low profit forests that cannot afford classical inventories. It will also provide a powerful tool for the conservation of natural protected areas threatened by deforestation or illegal practices, even when these areas are difficult to access.

CONFLICT OF INTEREST

The author (editor) declares no conflict of interest, financial or otherwise.

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