An Unpiloted Aerial System (UAV) Light Detection and Ranging (LiDAR) Based Approach to Detect Canopy Forest Structure Parameters in Old-Growth Beech Forests: Preliminary Results

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Abstract. Due to the increasingly rapid trend of biodiversity loss triggered by global changes and considering the critical role played by forests in conserving biodiversity, it is of great interest the study the structural attributes of natural forest stands. Understanding forest structure parameters, such as canopy height vertical variation, is crucial in acquiring information about natural forest dynamics. Recently, unpiloted aerial systems (UAV) have been used for mapping forest structure parameters. Among these, light detection and ranging (LiDAR) sensors are gaining attention. The main aim of this study is to test the feasibility of using UAV-based LiDAR surveys in detecting and mapping forest structure heterogeneity of primary old-growth beech forests. UAV survey has been conducted by means of the Zenmuse L1, equipped on board of the multirotor DJI Matrice 300 RTK in two small plots of the old-growth beech forest of Val Cervara, within the Abruzzo, Lazio, and Molise National Park in Italy. The acquired data have been processed to obtain the canopy height model (CHM). CHMs maps showed marked differences in canopy height spatial pattern between the two sample plots. Plot 1 showed a one-layered canopy density curve and a higher number of trees, while Plot 2 was characterized by a bimodal canopy layer with a lower number of trees. The proposed approach, even if still a first attempt, could be proposed as tool for mapping and monitoring old-growth beech forests.

Keywords: Remote Sensing (RS) · *Fagus sylvatica* L. · Canopy Height Model (CHM)

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O. Gervasi et al. (Eds.): ICCSA 2023 Workshops, LNCS 14112, pp. 197–205, 2023.
https://doi.org/10.1007/978-3-031-37129-5_17

1 Introduction

Due to the increasingly rapid trend of biodiversity loss triggered by global changes [1, 2] and considering the critical role played by forests in conserving biodiversity and ecosystem services [3], it has now become of great interest the study the structural attributes of natural forest stands, in order to better describe their dynamics from a management and conservation perspective [4]. Understanding these dynamics means figuring out how a forest performs without anthropogenic disturbances. In old-growth stands, stand structure is related to the long-term ecological dynamics that govern the trees' death, regeneration and growth [5]. Small-scale natural disturbances often drive these dynamics causing the opening of single tree-fall gaps that influences the forest structure [6, 7] generating a complex canopy structure linked to high biodiversity [8]. Thus, understanding different forest structure parameters, such as the distribution and the shape of gaps [9], the canopy cover [10], and the canopy height vertical variation [11] is a crucial step to acquiring information about natural forest dynamics.

As the most widespread forest type in Europe [12], the primeval European beech forests are the object of several monitoring activities aimed at studying their dynamics after disturbance events [13–16]. Acquiring data about canopy structure parameters with terrestrial field survey campaigns is time-consuming [17]. In the last decades, remote sensing (RS) techniques, especially those related to the use of very high-resolution (VHR) data, have been shown to be able to achieve good results with high accuracy levels [18–22]. Recently, the use of unpiloted aerial system (UAV)-based surveying results have been used for mapping forest structure parameters [23, 24]. Among these, the use of light detection and ranging (LiDAR) sensors is gaining attention among researchers and practitioners [25–30].

The main aim of this study is to test the feasibility of using the UAV-based LiDAR surveys novel approach in detecting forest structure heterogeneity of old-growth beech forests in relation to past severe disturbances (e.g. avalanches), to support and enhance forest ecology and monitoring research. The proposed method was tested in two plot areas (1.39 ha) of the old-growth beech (*Fagus sylvatica* L.) forest of Val Cervara, within the Abruzzo, Lazio, and Molise National Park in Italy.

2 Materials and Methods

2.1 Study Area

The study area (Fig. 1) is the old-growth forest of Val Cervara. It is located inside the Abruzzo, Lazio, and Molise National Park and falls in the Abruzzo Region at an altitude between 1530 and 1900 m a.s.l. The forest is dominated by European beech (*Fagus sylvatica* L.) and is characterized by a mosaic of primary old-growth structural patches in different phases of development from seedlings to senescent and dead trees, with ancient individual trees of up to more than 600 years of age [31]. It is distributed over 24 ha, with an uneven age structure on soils developed on calcareous bedrock. In 2017, the forest was included in the UNESCO World Natural Heritage (UNESCO WH) of serial sites "Ancient and Primeval beech forests of the Carpathians and other regions of Europe" (https://whc.unesco.org/en/list/1133/ – last access 2023/04/21) for

its exceptional ecological value. One of the plots was disturbed by an avalanche while the other show a typical complex structure linked to fine-scale disturbance.

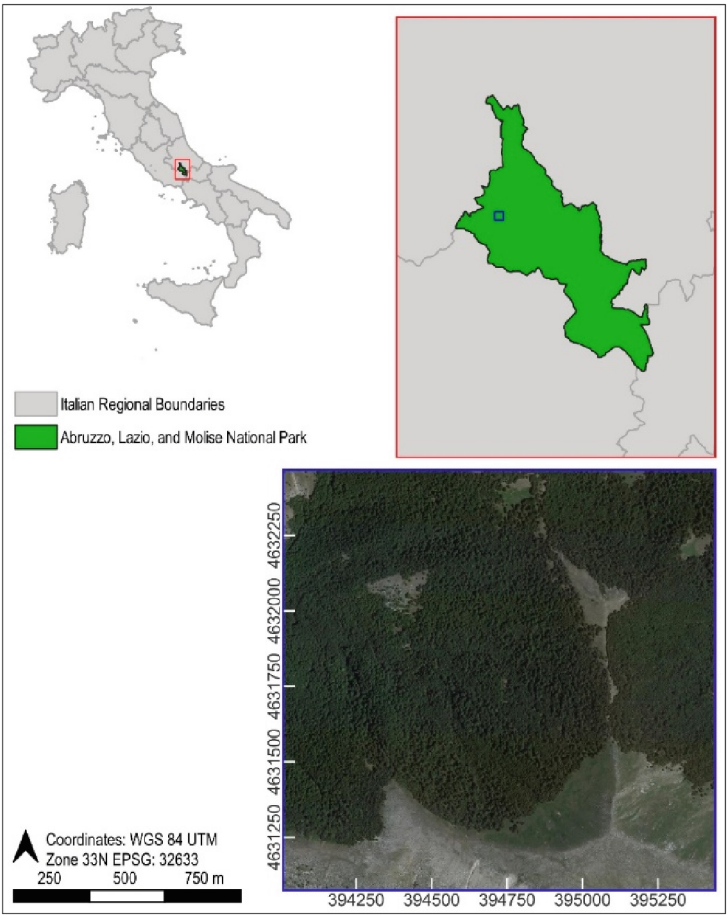

Fig. 1. Geographical location of the study area located in Val Cervara, inside the Abruzzo, Lazio and Molise National Park, in Abruzzo Region.

2.2 UAV Survey and Data Processing

The UAV survey has been conducted by means of the Zenmuse L1, equipped on board of the multirotor DJI Matrice 300 RTK on a 3-axis stabilized gimbal (Fig. 2). The Zenmuse L1 is a multisensory system, composed of three different sensors. The first one consists of a LiDAR sensor supporting 1 to 3 returns. The second one is an RGB camera used to collect photos obtaining true color 3D point-clouds. The last one is a high-accuracy inertial measurements unit (IMU), able to constantly check the flight parameters of the UAV during the flight.

The flight was conducted in a semi-automatic way. Taking-off and landing operations have been performed manually by the remote pilot, while the surveying flight was automated following a predetermined path. The height was set at 100 m a.g.l. and throughout the whole flight, the weather conditions (i.e., wind and light) remained constant. To improve the relative accuracy, the survey was performed using the high-precision GNSS mobile station D-RTK2 supporting all major global satellite navigation systems and providing real-time corrections.



Fig. 2. LiDAR sensor Zenmuse L1 equipped on board of the multirotor DJI Matrice 300 RTK.

2.3 Forest Canopy Heterogeneity Analysis

The main processing steps concerned the individual tree detection (ITD) and crown delineation within the two plots, to provide useful information regarding the vertical structure and the main properties of the forest canopy. The LiDAR derived CHM (0.5 m resolution) was first smoothed with a 3 × 3 pixels smoothing window size (SWS) for delating spurious potential local maxima, and a tree height threshold was set to 2.0 m for ITD. Tree tops were detected using local maximum (LM) algorithm by a 5 × 5 pixels fixed window size (FWS). Tree crown delineation was then performed following Silva et al. [32] using the Voronoi tessellation-based algorithm. For each plot we obtained the CHMs canopy profile, and the height frequency distributions and single tree crown area statistics were then derived. For comparing stand structure heterogeneity, we made use of variability and asymmetry measurements of tree heights [33] by computing Lorenz curves from the cubic power of tree heights, which has been observed to relate to Lorenz

curves obtained from tree diameters [34]. Analysis was conducted using the treetop package [35] implemented in the R statistical software [36].

3 Results and Discussions

Results from a quick assessment of CHMs maps showed marked differences in canopy height spatial pattern between the two sample plots, highlighting a more complex structure for plot 2 (Fig. 3).

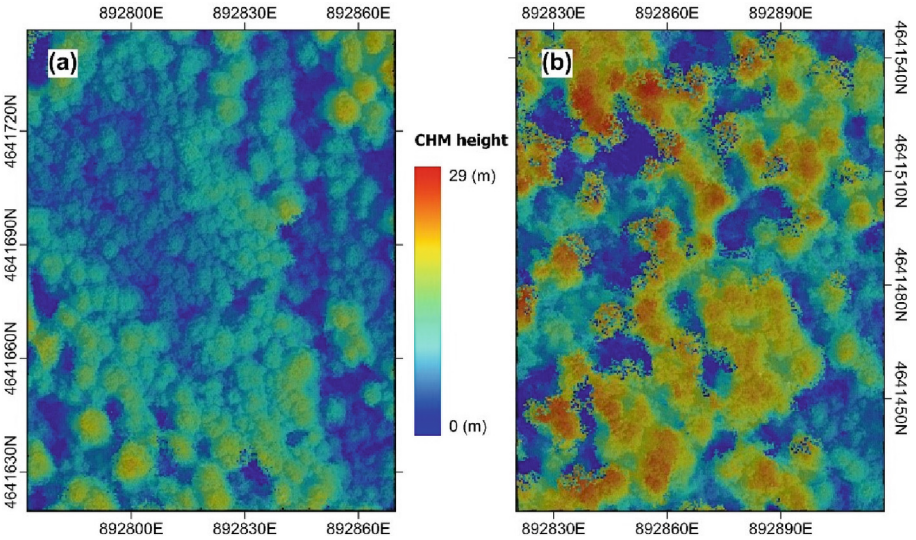

Fig. 3. LiDAR-derived Canopy height model (CHM) for plot 1 (a) and plot 2 (b) of the old-growth beech forest of Val Cervara (EPSG 32633 coordinate system).

Canopy metrics related to the plot confirm such differences. The maximum tree height was found in plot 2 (29 m) while in plot 1 reached 22 m (Fig. 4). Plot 1 showed a one-layered canopy density curve and a higher number of trees (456 canopy trees/ha) showing that this part of the forest was in the past disturbed by severe disturbance such as avalanches generating a unimodal and less-developed stands. Plot 2 was characterized by a bimodal canopy layer with a lower number of trees (244 canopy trees/ha), with the majority reaching the top of the canopy (Fig. 4). This more uneven-aged structure is the result of fine-scale disturbance driven single tree death where canopy gap pattern shapes tree recruitments. The greater space available for the trees reflects in the greater dimensions of the tree crowns of this plot. This complex vertical profile was also reported in other studies [5, 20] and seems to characterize the structure of old-growth beech forests where long-term growth dynamics are driven by fine-scale disturbances.

In our study, we chose to evaluate canopy heterogeneity in the canopy height, because tree height above the ground was the variable directly measured by the LiDAR.

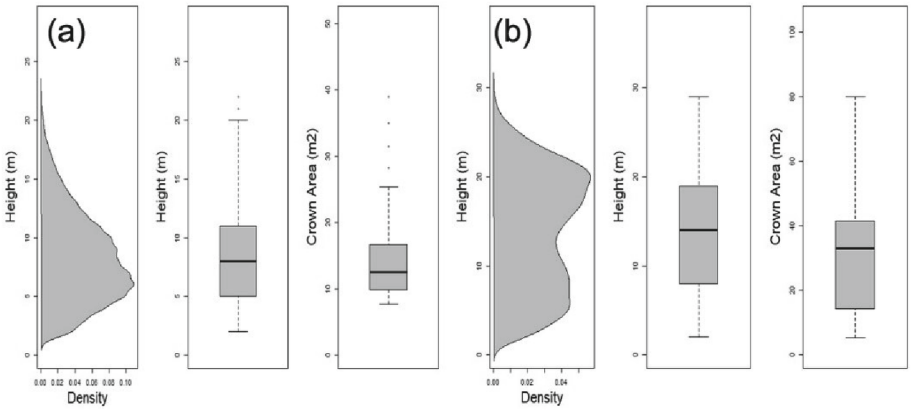

Fig. 4. Canopy height density profile, tree height density distribution and crown area density distribution from LiDAR-derived Canopy height model (CHM) for plot 1 (a) and plot 2 (b) of the old-growth forest of Val Cervara.

The Lorenz curve for the two plots (Fig. 5) showed an unequal distribution of canopy height as it lies above the line of absolute equality, suggesting different degree of homogeneity in their structure. The upper part of the shaded area shows the position of a Lorenz curve representing the maximum entropy over the Lorenz plot. It can be observed that plot 1 showed a lower variability in tree height by the low amplitude of its Lorenz curves, close to the diagonal (absolute equality) (Fig. 5).

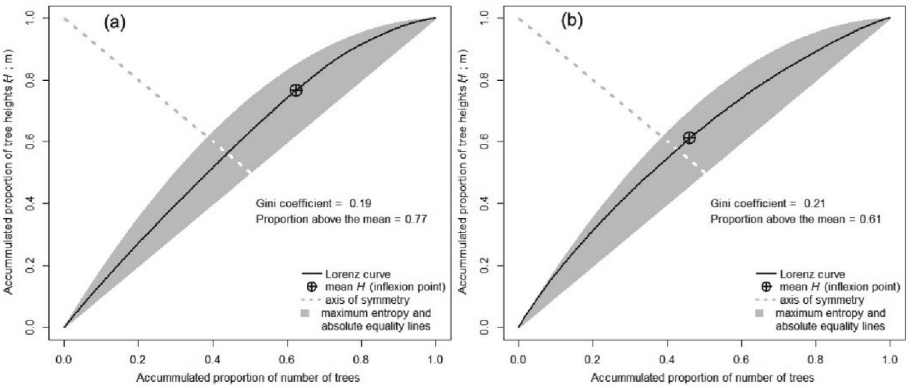

Fig. 5. Lorenz curve plot of LiDAR-derived tree heights for plot 1 (a) and plot 2 (b) of the old-growth forest of Val Cervara.

The Gini coefficient (GC) calculated as the ratio between the area enclosed by the equality line and the Lorenz curve, and the total area under the line of equality, obtained from both of stands was 0.19 and 0.21 respectively. Coefficient values confirms the Lorenz curve results [37]. The higher the coefficient, the more unequal the distribution

is, suggesting that severe forest disturbance decreases GC, whereas fine-scale disturbances and seed regeneration increases GC [38], and therefore gap dynamics could be characterized by shifts between hypothetical GC thresholds.

More apparent differences between the two beech forest plot can be observed when considering the measures of asymmetry. As suggested by Damgaard and Weiner [39], we evaluate the asymmetry of the Lorenz curve by comparing the position of its inflexion point against the axis of symmetry, specifically the location of the point at which the Lorenz curve has the same slope of the line of equality. Results reveals that plot 2 has a much more heterogeneous structure as the skewness of the Lorenz curve indicates understory development which is reflected by its uneven-sized tree height.

4 Conclusions

In this paper, which shows the preliminary results of still ongoing research, we used a UAV LiDAR-based CHM approach to detect forest structure heterogeneity in primary old-growth beech forests, to support studies in forest ecology and enhance monitoring research in this global change era. The differences shown by the two plots with different disturbance histories highlighted that the two different situations are easily detectable by the surveyed structure parameters. Further analyses and surveys are needed to refine the proposed method, also considering other indices. However, the analyses already presented in this study support the UAV approach as a tool for mapping and monitoring old-growth beech forests.

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