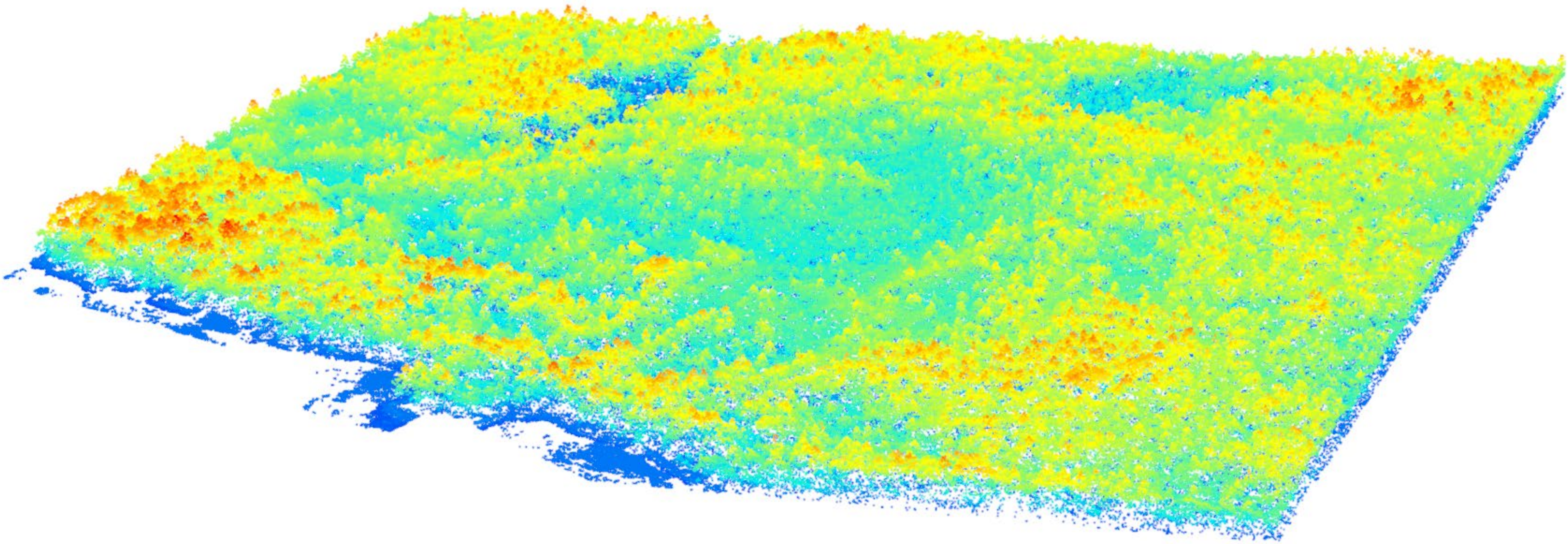
MAPPING TREE DYNAMICS IN 3D

The Petawawa Research Forest case study



TOMMASO TROTTO

BACKGROUND

My name is Tommaso Trotto and I am currently a PhD candidate in the Integrated Remote Sensing Studio under the supervision of Dr. Nicholas Coops. My undergraduate studies focused on Forestry at the University of Padova, Italy. I completed my Master's double-degree at UBC in Master of Forestry. My current interest is in the application of remote sensing technologies to understand the resistance and resilience of various forest types, such as coastal, temperate, and boreal, to non-stand replacing disturbances, especially in eastern Canada. To achieve my PhD project's goal, I mostly rely on time series of Light Detection and Ranging (LiDAR) data, known as point clouds. LiDAR is a cutting-edge technology for the appreciation of vertically distrusted attributes in forested landscapes. LiDAR offers unprecedented 3-dimensional insights into the complexity of forests, shedding light on, for instance, the dynamics of stand structure as a consequence of natural forest disturbances.

INTRODUCING THE PROBLEM

Forest disturbances have been forecast to exacerbate in severity, spread, and frequency[1]. As a consequence of disturbance regime exacerbation, and uncertain future scenarios, a thorough understanding of the resistance and resilience of forests is of uppermost importance. In recent literature, authors have highlighted the influence of forest structure on forest resistance and resilience to natural disturbances[2,3]. However, a punctual assessment of what specific structural attributes are involved in such a process has yet to be proposed. In this respect, LiDAR time series of pre- and post-disturbance forest conditions are valuable for a spatially-explicit detection of the influence of forest structure on natural disturbances. The possibility to study the 3-dimensional change in forest structure due to disturbances would permit the assessment of the most sensitive structural traits involved in the resistance and resilience to disturbances and thus inform forest managers on strategies to reduce the vulnerability of their forests to such events.

LiDAR point clouds are not of easy interpretation. Extensive manipulation is often required to make them accessible to end-users. The easiest and most user-friendly approach is the construction of maps showing key features of interest. In this regard, ArcGIS provides a comprehensive platform for LiDAR data manipulation and seamless integration with peer-reviewed LiDAR processing tools such as LAStools by rapidlasso GmbH. LAStools permits fast processing of LiDAR point clouds while ArcGIS offers visual support. For the project here proposed, ArcGIS and LAStools were used to produce a map of tree height variation, along with canopy density change, in the form of a Canopy Height Model (CHM) for the Petawawa Research Forest (Ontario, Canada) between 2005 and 2018. Tree height and density were chosen because are standard metrics in forest inventories and they are traditionally included in silvicultural prescriptions, thus directly manageable. Ultimately, the proposed map represents an initial step toward a better understanding of the variations in tree height and density across the Petawawa Forest which, in combination with ancillary data on natural disturbance regimes, would allow managers to formulate silvicultural prescriptions aimed at improving forest resistance and resilience by fostering structural attributes that are considered resistant and resilient to such disturbances[4]. This project is related to my PhD for the methodology applied, rather than for the underlying concept.

THE PROCESSING OF LiDAR POINT CLOUDS

The proposed map was produced from two discrete and classified LiDAR datasets (2005, 2018). Due to inconsistencies in point density and ground reference, the LiDAR data (LAS files) were harmonized to match ground level and point density. Each LAS file was scanned for duplicate points (**lasduplicate**), and noise (**lasnoise**). Point cloud normalization was performed with **lasheight**, which served as the basis for the construction of the two CHMs with **lasgrid**. The resulting CHMs were sampled at 5m spatial resolution to match with an available Digital Elevation Model (DEM) of the area. To produce the map of tree height variation, the 2018 CHM was subtracted to the 2005 CHM with **Raster Calculator**. In conclusion, a low pass filter and the **Boundary Clean** tool were applied to reduce noise and improve the aesthetic of the map. The change in height was colored in a gradient of green to recall natural vegetation, with a more intense color representing the highest increase in tree height over the 13 years, further overlaid onto a brown-colored DEM to render the effect of a 3-dimensional ground. Tree height change was expressed in positive values only, as loss in tree height was minimal. Values ranged from 1 – 4m height increment. Only an increase in tree height >1m was colorized to improve the readability of the map and to highlight tree height increment hotspots, as an increase equal to 1m was observed to occur throughout the entire area.

The tree density map was calculated with **lascanopy** and sampled at 400m resolution due to high variability in pixel value and secondly because a map of tree density variation was not the primary goal of this project. The resulting raster was polygonized using the **Raster to Polygon** tool, then exported to R (R Core Team, 2022) for further manipulation. Polygons were chosen over raster to present more variability in data type and look. In R, a subset of density values was selected from the polygonized raster to include only the most representative data based on the distribution of density values. Loss in tree density was set at ≤0% (0 - -10%), whereas the increase in tree density was set at ≥5% (5 - 10%). The spatial location of tree density increase was hypothesized to be a consequence of high tree regeneration, whereas loss in density may have been a consequence of competition and subsequent tree mortality due to growing trees. The resulting subset of polygons was merged into a single-polygon feature and then smoothed using package **`‘smoothr’`** in R for aesthetic purposes. In ArcGIS, the loss in tree density over the 13 years was displayed in red, whereas the increase in tree density was proposed in green for better readability.

Thanks to better software integration, it is possible to expand the analysis of spatial data to statistical software such as R or Python, and produce accurate and easy-to-interpret graphics, as more spatial-processing packages are being made available. Such integration permits faster data processing for researchers and thorough statistical analysis of the data. An example of such integration is proposed in Figure 1, where package **`‘lidR’`** was used in R to produce a vertical profile of a sub-portion of the study area. Furthermore, in R or Python, it is possible to study and visualize the relationship between variables, for example, elevation and tree height variation (Figure 2).

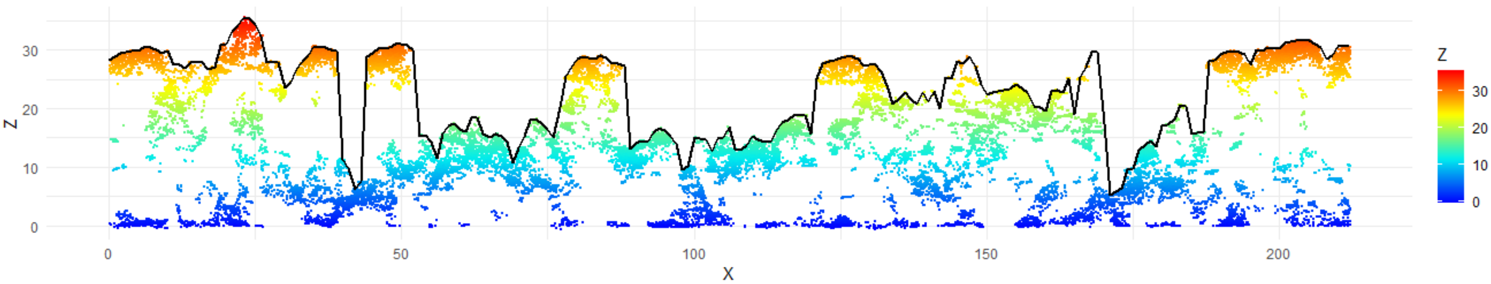


Figure 1. Representation of a normalized transect of the Petawawa Research Forest using package **`lidR`**. *LiDAR offers incredible details on the 3-dimensional distribution of structure and vegetation strata in a spatially-explicit fashion. Points were colorized by height, and a Digital Surface Model (DSM) was drawn on top to delineate the vertical profile of a forest transect. Depending on the density of points in the LiDAR point cloud, lower or higher penetration degrees are achieved, which ultimately influences the accuracy of the resulting DSM.*

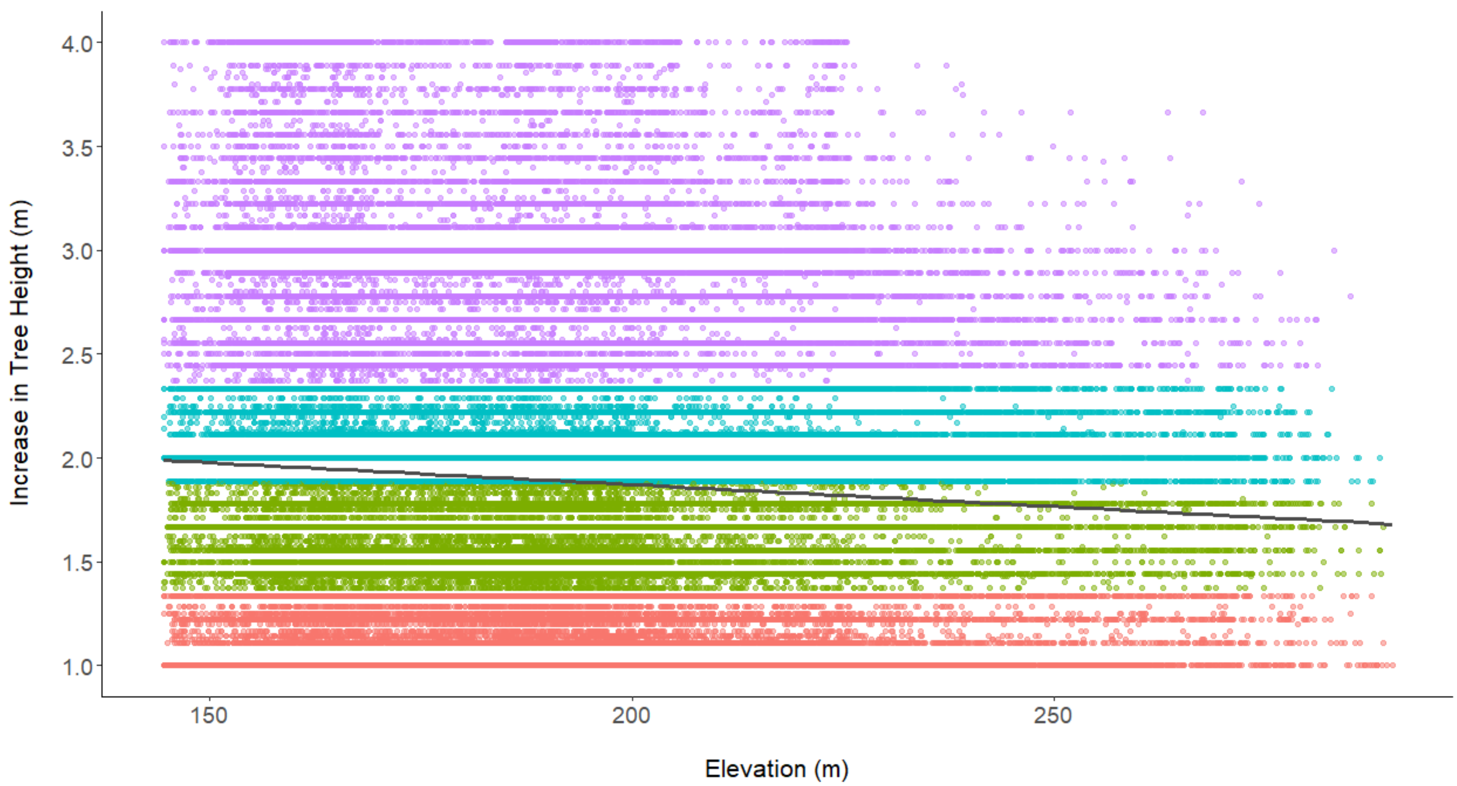
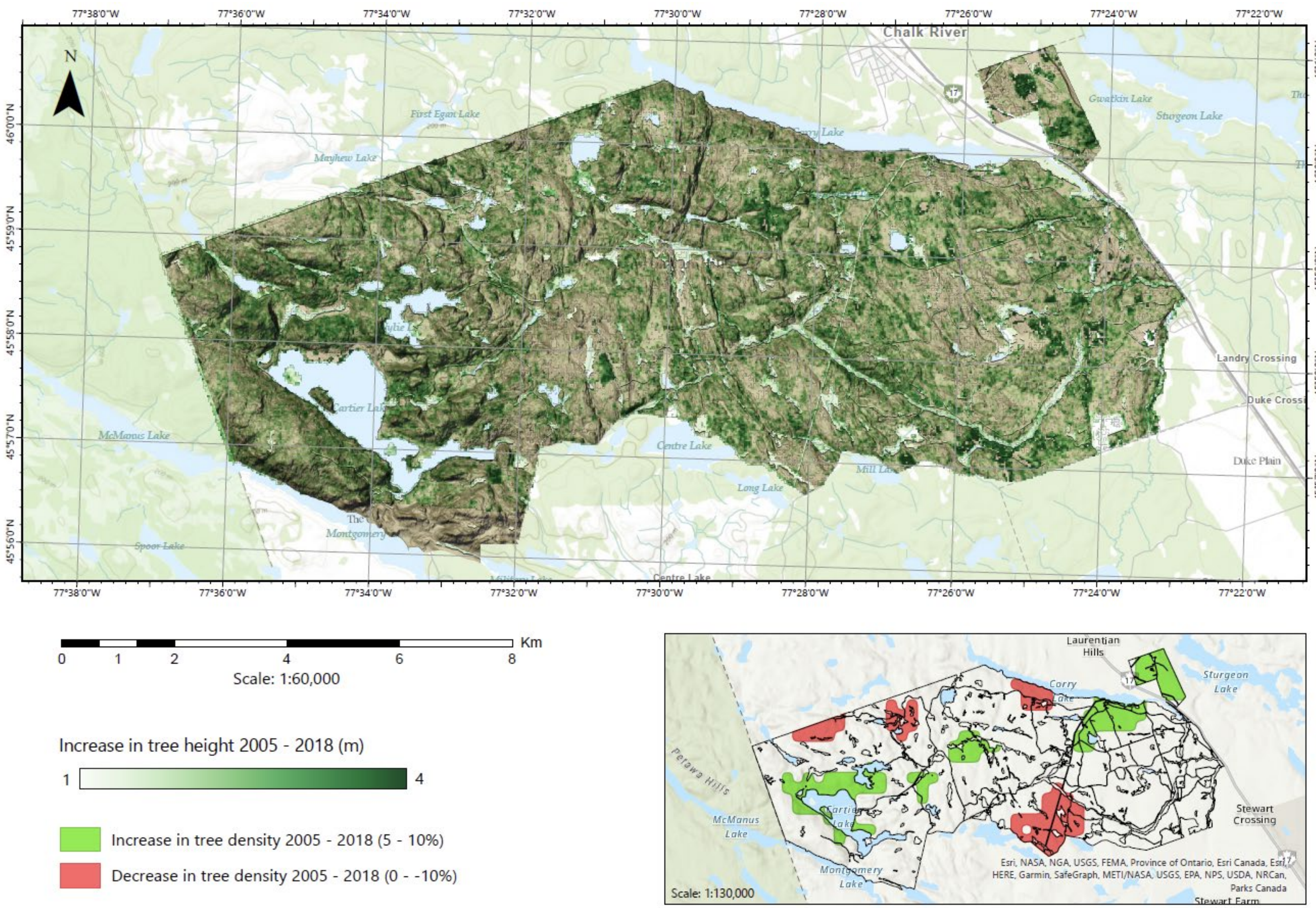


Figure 2. Graph of the relationship between Elevation (m) and Increase in Tree Height (m) between 2018 and 2005. Points are distributed towards low values and an increase in elevation seems to reduce tree height increment, although the relationship is very weak (r^2 <0.01). The dark grey line shows the fitted statistical relationship between the variables. Points are colored based on percentiles (0^{th}-25^{th}, 25^{th}-50^{th}, 50^{th}-75^{th}, 75^{th}-100^{th}) and a shading effect was applied for a better aesthetic.



Map of the Petawawa Research Forest, developed in partial fulfillment of the requirements for the ESRI Scholarship promoted by The University of British Columbia. The map, analysis, and report were produced specifically for the present scholarship. The analysis I conducted was helpful for my PhD as it helped me to improve my knowledge around the use of ArcGIS and LAStools.

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