EGU2020: Sharing Geoscience Online conference 4 - 8 May 2020

Extrapolating a spatially explicit tree root reinforcement model with field and LiDAR-derived stand data

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ABSTRACT

Tree roots can prevent landslides through root reinforcement. Modelling root reinforcement means combining density and biomechanical properties of the roots. Slope stability analysis requires the estimation of root reinforcement on large areas. In the present study, we analyze the relationship between a spatially explicit model of root reinforcement and LiDAR metrics from a sample of Norway spruce stands. Data were collected in twenty 20-m radius circular plots covered by a low-resolution airborne LiDAR-derived canopy height model. Trees diameter and position were used as input variables to calculate root reinforcement. Then, we fitted the relationship between root reinforcement and area-based stand metrics from canopy height model. Best regression was achieved plotting root reinforcement against canopy height model-derived tree height standard deviation (R^2 = 0.73; relative RMSE = 0.096). Therefore, root reinforcement values might be spatially extrapolated through available canopy height models. Further research will integrate the extrapolated values into landslide susceptibility models.

Introduction

Tree root systems are effective in preventing shallow landslides. The roots produce various mechanical effects that can be summarised in the well known "root reinforcement" (measured in Newton, N) (*Sidle and Ochiai*, 2006). The root reinforcement is commonly quantified using models which combine roots density and distribution with the biomechanical properties of the roots (*Chiaradia et al.*, 2016). Slope stability analysis requires the estimation of root reinforcement on large areas. LiDAR data, collected with airborne laser scanning (ALS), have been frequently used to assess various standing forest parameters. Parameters such as growing stock, stand volume and stand height are derived, with good results, from area-based method applied on large forest areas (*Eysn et al.*, 2008). The aim of this work is to display that area-based method can be used to extrapolate, to large forest areas, root reinforcement data. In particular, we used the root reinforcement spatially modelled from field data as dependent variable and height stand metrics, extracted from LiDAR, as independent variable. The derived empirical model was used to spatially extrapolate the root reinforcement into large maps.

Materials and Methods

In the summer of 2019, a sampling campaign was conducted in higher Valcamonica, Southeastern Alps, Italy. Stand data were collected in twenty 20-m radius circular survey plots with a steepness ranging between 20-40°. The altitude ranges from 800 to 1400 m asl. The plots were covered by low-resolution (1-2 point per m^2) LiDAR data. All living trees (if DBH ≥ 7.5 cm) inside the plot were measured for: position (x and y coordinates), DBH (Diameter at Breast Height) and tree height. DBH and position were used as input variables to calculate root reinforcement in the MATLAB package "rootFORCE". The package combines the Root Distribution Model (RDM) and the Root Bundle Model Weibull (RBM_w). In each plot, an average value of root reinforcement (RR_m) was computed. Afterwards, we built a canopy height model (CHM-derived tree height) from LiDAR data. A set of raster statistics were extracted from CHM-derived tree height for each plot (*Scrinzi et al.*, 2015): CHM-derived tree height mean (h_{mean}), median (h_{med}), max (h_{max}), min (h_{min}), and standard deviation (h_{sd}). RR_m was plotted against each raster statistic in order to evaluate the best regression (R^2 adjusted value and relative RMSE). The raster statistic were extracted through the zonal statistic tool of the opensource software QGIS. Maps of the extrapolated root reinforcement were built with QGIS. We used square cells of the same dimension of the survey plots.

Results and discussion

The RR_m ranged from 6208 N to 13111 N (mean = 8409 ± 1626) and showed a high variability due to differences in density, stand development stage, DBH distribution. Best adjusted R^2 and relative RMSE were achieved plotting RR_m against h_{sd} (R^2 = 0.73; relative RMSE = 0.096) (Figure 1). The derived equation of exponential curve was:

$$RR_m = \alpha \cdot e^{\beta \cdot hsd}$$

where α and β are respectively 5168 and 0.071. Appliyng the above-mentioned equation to each square cell of the study area, where the h_{sd} values were previously calculated, we spatially extrapolated the root reinforcement values to the entire study area where Norway spruce forests and LiDAR data occur (Figure 2). Despite the feasibility of this procedure requires to be better explored, we advocate its usefulness especially when

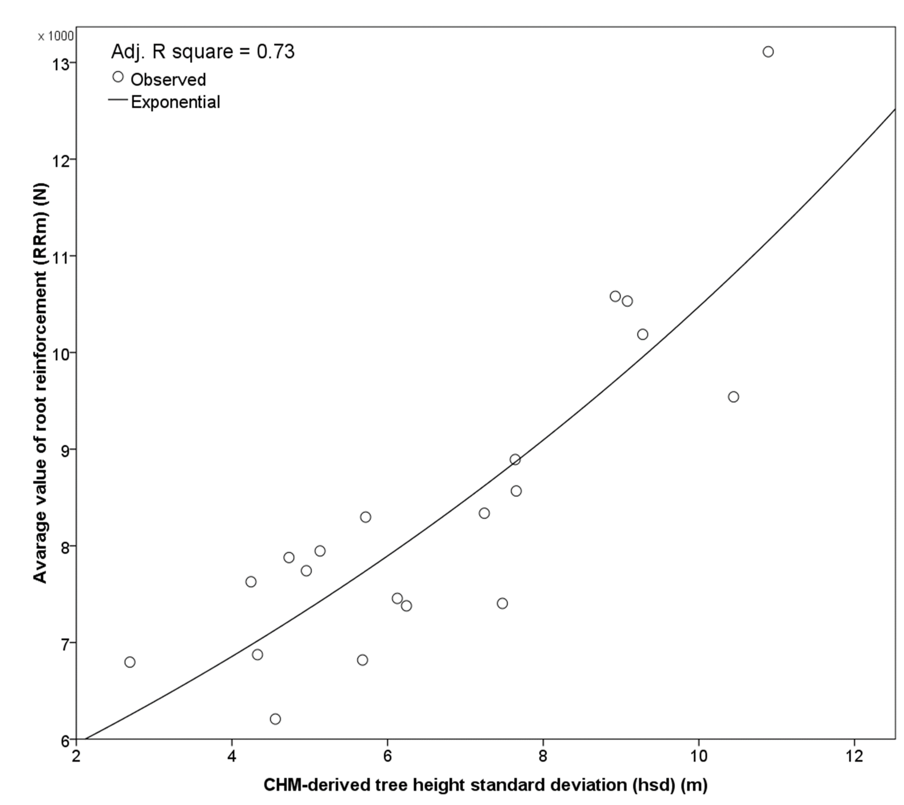

Figure 1. Regression curve between the variables CHM-derived tree height standard deviation (h_{sd}) and average value of root reinforcement (RR_m) in each survey plot.

large spatial estimations of root reinforcement are needed for landslide modelling. Further step is to integrate the extrapolated values into landslide susceptibility models, which combines other data available from forest plans, digital elevation models, geological and meteorological data. Similar studies could provide managers with a tool to periodically update maps of the service given by forest trees to protection of humans from landslides.

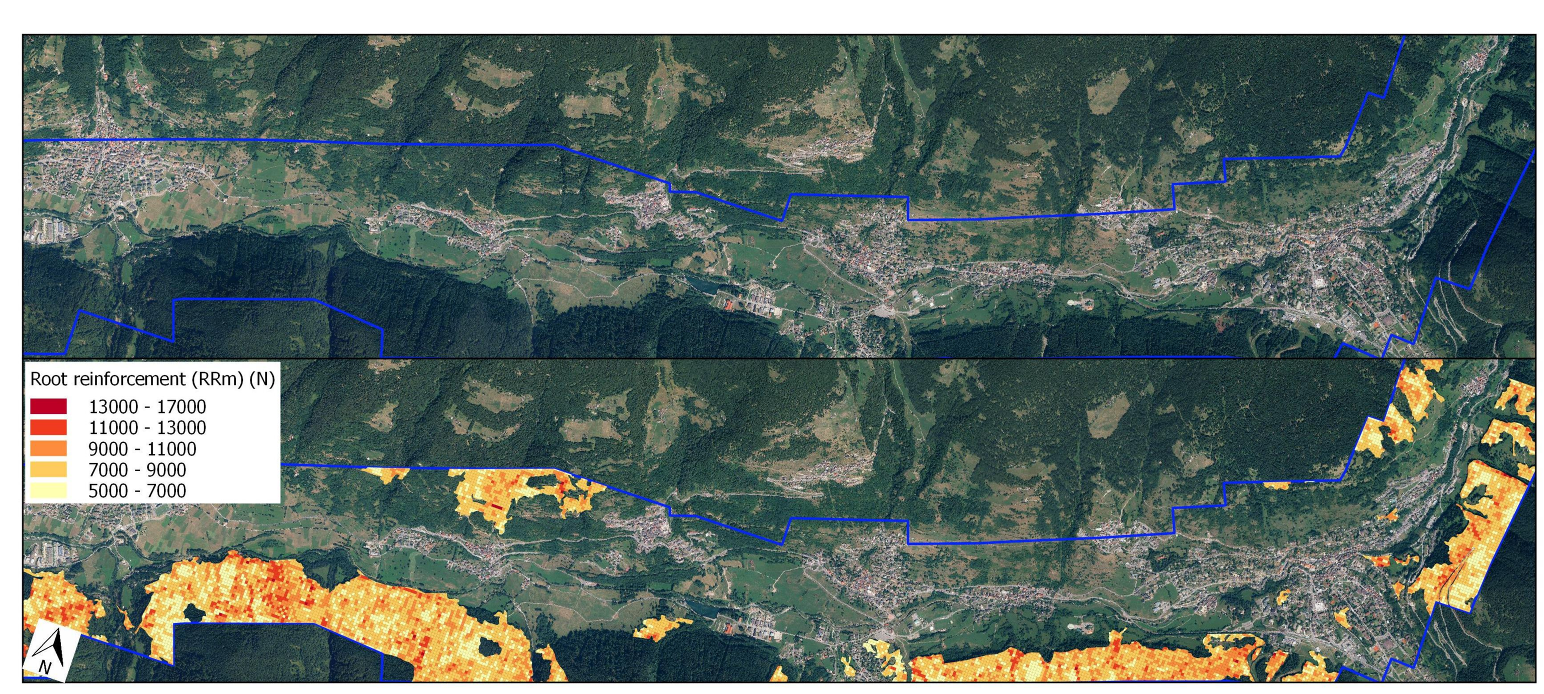

Figure 2. Map of the spatial extrapolated root reinforcement. LiDAR data were available inside the blue bounded area.

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This research was an integral part of the project **TREE:HERO**, acronym of "**TREE distribution patterns: HillslopE failuRe preventiOn through forest management**", entirely funded by Fondazione Cariplo (Italy; Ref. 2017-0714) https://www.unimontagna.it/progetti/tree-hero/