Developing a method for forest structure analysis by using a photogrammetric approach

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Introduction

Investigating the characteristics and the distribution density of both canopy trees and understory vegetation is key for understanding hydrological processes and forest development management. Changes in stand density affect major hydrological processes (*Fig. 1*) such as Interception Loss (E_i), Throughfall (*Tf*), Stemflow (*Sf*) and Transpiration (E_t). For instance, *Nanko et al., (2016)* revealed that the decrease in stem density from 2400 to 1300 trees ha^{-1} and basal area from 107.6 to 60.4 m^2 ha^{-1} in a Japanese cypress plantation, increased the *Tf* fraction from 58% to 79%, and decreased the *Sf* fraction from 14% to 8.6% and the E_i fraction from 27% to 12%. Also LAI is among the most important variables in forest hydrology analysis. Throughfall tend to decrease with increasing LAI, as an evidence that the number of leaves plays an important role in *Tf* ratio (*Deguchi et al., 2006*). Increase in LAI from 2.7 to 4.42 increased interception loss of 23% (*Park et al., 2000*). Decrease in stand density by 43-50% due to thinning caused an increase in mean *Tf* rate from 63.2 ± 7.0% to 75.4 ± 6.0% (*Sun et al., 2017*).

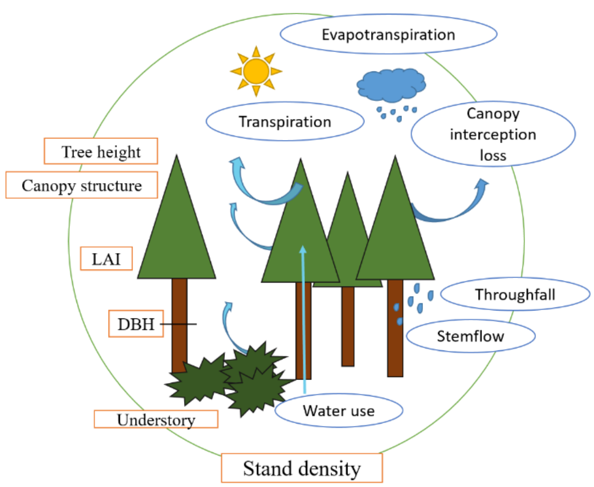

Figure 1: Changes in stand density affect major hydrological processes. Hydrological processes are represented in oval boxes, while in rectangular ones are represented main forest structure variables.

Although the investigation of forest stand conditions is important, traditional inventories consisting in direct field measurement of tree heights and diameters (DBH) are considered laborious and time-consuming (*Mielcarek et al., 2020*). Therefore, large-scale forest measurements, which are required for watershed management, are particularly challenging. In order to overcome these problems, Remote Sensing (RS) techniques are effective. Satellite RS has enhanced forest assessments on very large scales but the spatial resolution often limits its use for forest monitoring purposes. Recently, airborne LiDAR technology, also referred to as Airborne Laser Scanning (ALS), has dramatically increased the level of detail and accuracy of forest information by providing three-dimensional (3D) data of forest structures (*Goodbody et al., 2019*). However, LiDAR application is still very expensive and high temporal resolution surveys are cost-restrictive.

Lately, Unmanned Aerial System (UAS) Structure from Motion (SfM) Photogrammetry, has been increasingly adopted for forest research, as it provides similar accuracy to ALS but with significant operational and costs advantages (*Osborn et al. 2017*). SfM photogrammetry enables the generation of 3D point cloud from a set of overlapped digital images, without the need to specify camera positions or orientation (*Westoby et al., 2012*). For example, *Iizuka et al., (2018)* used drone SfM method to estimate tree height and DBH in Japanese cypress forest. By comparing the estimations with field measurements they found they could estimate tree height with RMSE = 1.712 m. They also found that DBH was highly correlated with canopy width (R^2 = 0.7786) and canopy area (R^2 = 0.7923). Also *Panagiotidis et al., (2016)* find good agreement between field and remote-sensed tree heights (RMSE% 11.42-12.62) and crown diameters (RMSE% 14.29-18.56). *Puliti et al. (2015)* estimated Lorey's mean height, dominant height, stem number, basal area and stem volume with RMSE values of 13.3%, 3.5%, 39.2%, 15.4%, and 14.5% respectively. Although, being photogrammetry a passive RS technique, the possibility of exploring forest vertical structure (i.e. below the canopy) by using aerial imagery only, remains limited (*Rahlf et al., 2016; Osborn et al. 2017; Goodboy et al., 2019; Mielcarek et al., 2020*).

In this study we use aerial digital images collected with UAS platform and processed with SfM technique, for estimating the hydrology-significant forest structure parameters. Thereby, the objectives are i) to derive stand density, LAI, canopy structure, DBH and tree height information from the SfM generated 3D model; ii) to compare the estimated values with actual field measurements, thus assessing the accuracy of SfM method; iii) to compare forest conditions using data from previous years (i.e. 2012 and 2020).

Methodology

Study Site

The study site consists in a forest plantation of uneven Japanese cypress (*Chamaecyparis obtusa)* and Japanese cedar (*Cryptomeria japonica) (Fig 2a)*. The plantation is located in Mt. Karasawa experimental forest, in Sano, Tochigi prefecture (36°22'N, 139°36'E). The mean annual precipitation is 1232 mm with a standard deviation (SD) of 196 mm; mean annual temperature is 14°C, SD 1°C. The soil parent material consists of sedimentary rock (*Nam et al., 2014*). The surveyed area is located in K2 watershed and is 0.9 ha wide. The microtopography is generally complex and it is south/south-west exposed. The altimetry interval is comprised between 120-190 m AGL and the average slope pendency is 33° (*Fig. 2b*). From July to October 2011, 50% strip-thinning operation was carried out.

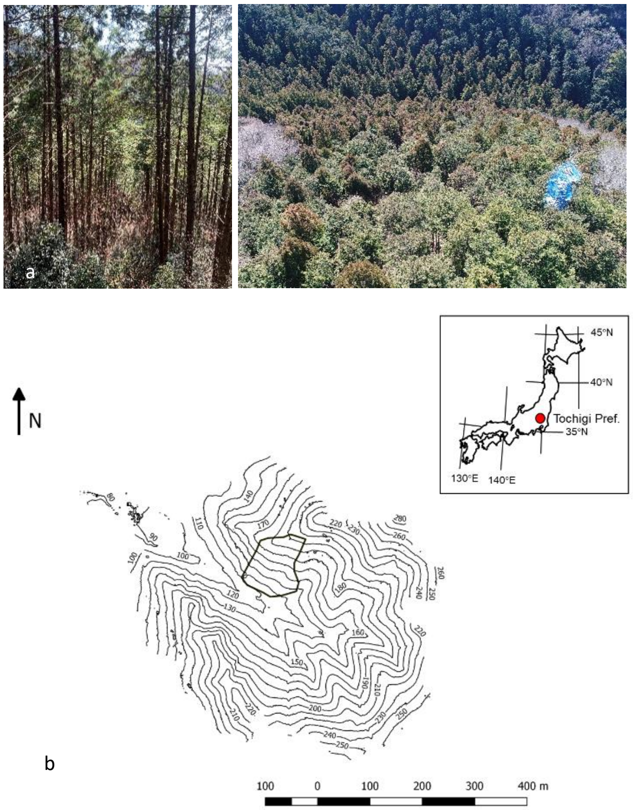

Figure 2: The surveyed area in Karasawa Forest a) Chamaecyparis obtusa *and* Cryptomeria japonica *plantation; b) study area location in K2 watershed.*

Methods

The images collected with UAS platform are processed with *Agisoft PhotoScan©* software, to derive both Digital Surface Model (DSM) and Ortophoto. The terrain information is provided by an already existing (2012) ALS Digital Terrain Model (DTM). By subtracting the DTM to the DSM in *ArcMap (ESRI, v. 10.6.1)* raster calculator, a Canopy Height Model (CHM) can be obtained (i.e. CHM = DSM – DTM). Single tree height and single crown area are extracted with *FUSION/LDV (USDA)* software. Then, stand density, LAI and DBH values can be derived. The estimations extracted from the CHM are compared with field measurements for evaluating the accuracy of SfM method. Three 10x10 m plots are used for sampling tree height, DBH, and LAI. The sampled trees are identifiable from the aerial images. Statistical analysis is performed to evaluate the difference between estimated and measured values. Furthermore, the same extracting method can be applied on 2012 and 2020 CHMs. Eventually, we can take a look on how stand density varied across the years and calculate the tree incremental growth in terms of height and diameter from 2012 to present day. Validation of the growth trend is performed with tree-ring analysis.

Results and Discussion

On one side, the expected results concern the estimation of the forest structure variables that are of interest for hydrologic analysis. On the other, the evaluation of the drone-SfM operational framework and concomitant parametrization for data processing, is also envisaged. Drone-SfM photogrammetry is by now widely implemented in forest analysis, and has proven to be consistently useful in forest inventories (*Iglhaut et al., 2019*). Indeed, the increase in surveys' temporal resolution is of great interest for deepening the understanding of forest ecosystem complex dynamics. It could also enhance forest stewardship and data-driven environmental policy-making (*Goodbody et al., 2019*). Accordingly, this method could be very promising for watershed-scale monitoring and management. Besides, numerous other environmental fields of applications are being tried-and-tested, e.g. geomorphic slope stability and landslides analysis.

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