Abstract template for the conference "A century of national forest inventories – informing past, present and future decisions"

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On page two, you are asked to fill in your abstract in the format and font size indicated. Please remember to include authors affiliation information in the footer section of page two. The length of the abstract may not be more than one page including references.

Abstract title:		Direct estimation of growing stock volume at plot, stand, and forest level using UAV-laser scanning data alone
Take-home message:		*In this study we demonstrate how UAV-laser scanning data alone can provide accurate and precise volume estimates in boreal conditions without the need of in-situ observations. The study opens new possibilities in forest mensuration and can have great impact both on forest management inventories as well global mapping efforts*
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General topic, see website: (please double click on the check box and activate the relevant one)		Improving future NFIs by learning from the past
		NFIs today and in the future
	x	Cutting edge and futuristic inventory techniques and technologies
Preferred presentation form:	x	Oral presentation
		Poster
Abstracts will be reviewed by members of our scientific committee and you will be given information on decisions in due time after the submission deadline has passed.		

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Direct estimation of growing stock volume at plot, stand, and forest level using UAV-laser scanning data alone

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Introduction: Laser scanning data from unmanned aerial vehicles (UAV-LS data) offer new opportunities to directly measure single tree biophysical variables and supersede the need of acquiring field reference data. While previous research demonstrated the possibility to obtain direct measurements of tree biophysical variables for a selected number of trees, it remained unclear how such measurements can contribute to the estimation at plot, stand, and forest level. In this study, we developed a new method to estimate growing stock volume (m^3 ha^{-1}) at different spatial scales using UAV-LS data alone.

Materials and methods: We used UAV-LS data collected using a Riegl-VUX 1 sensor with an average point density of 1130 points m^{-2}. In addition to the remotely sensed data, 58 sample plots were measured in the field for independent validation with current state-of-the-art. Using the UAV-LS data alone we 1) detected and segmented single trees, 2) measured diameters at breast height (DBH) of detected trees, 3) selected two separate samples; one with reliable DBH measurements, one where tree species could be visually interpreted, 4) modelled DBH and tree species and predicted them for all detected trees, and lastly 5) used predicted single tree DBH, species, and tree height (i.e. 95th height percentile) to predict single tree volume based on species-specific allometric functions. The single tree volumes were then aggregated to either plot, stand, or forest level and these estimates compared to the 58 independently measured field plots, aggregated into 14 stands within a contiguous forest area. Furthermore, the precision of the UAV-LS estimates was assessed by adopting a non-parametric boostrapping estimator.

Results: The root mean square difference as percentage of the mean ($RMSD_{\%}$) decreased when increasing the spatial scale from plot level (32.2%) to stand (27.1%) and forest level (3.5%). The $RMSD_{\%}$ was in all cases smaller than the standard deviation (SD at plot level) or standard error ($\overline{SE}$ at stand and forest level) of the field-based estimates, suggesting that UAV-LS were more precise than a field survey with a sampling fraction of 16.7%. The estimates based on UAV-LS data were always well within the 95% confidence intervals of the field-based estimates. At forest level, the precision of the UAV-LS estimates according to the bootstrapping procedure was of similar magnitude (18.0 m^3 ha^{-1}) as the field-based estimate of the standard error (18.6 m^3 ha^{-1}).

Conclusion: Overall, this study demonstrated that UAV-LS data can be used to directly measure DBH for a sample of trees and how such a sample can be used to estimate V at plot, stand, and forest level. The main merit of this study was the introduction of a novel workflow through which scattered but high-quality UAV-LS measurements can be used to model V for each single tree in the area of interest. While our results are encouraging for further use of UAV-LS in a context of fully airborne forest inventories, it remains necessary to confirm these findings in a wider range of forest types.

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