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

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Abstract title:		Mixed-effects models to generalize sample tree height information: implications to national forest inventories
Take-home message:		*Mixed-effect models with plot-specific calibration using random effects are a perfect tool for imputation of tree heights in a forest inventory. The Näslund's and Curtis functions are good two-parameter functions for the relationship. R-package lmfor includes easy-to-use functions for imputation in practical inventories.*
Presenter name:		Lauri Mehtätalo
Presenter contact info:		University of Eastern Finland, P.O.Box 111, 80101 Joensuu. Finland. lauri.mehtatalo@uef.fi
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
	☐	Cutting edge and futuristic inventory techniques and technologies
Preferred presentation form:	☒	Oral presentation
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Mixed-effect models to generalize sample tree height information: implications to national forest inventories

Lauri Mehtätalo[1], Timothy G. Gregoire[2] and Sergio de-Miguel[3]

Introduction: Individual tree heights are needed in many situations, including the estimation of standing volume, biomass, or change in them in national forest inventories. However, height measurements are tedious compared to tree diameter measurements, and therefore height–diameter (H–D) models are commonly used for prediction of tree height.

National forest inventories often use a two-phase sampling method (also known as double sampling) for tree characteristics. In that method, all trees of a sample plot are measured for tree diameter and species in the first phase, but only a subsample of them is measured for other characteristics, such as tree height in the second phase. It is common that the relationship between the second-phase and first-phase characteristic varies between plots or clusters of plots. A theoretically justified way to generalize the sample tree information in such situation is the mixed-effect model calibration (Lappi et al 2006).

Previous studies have fitted H–D models using approaches that include plot-specific predictors in the models and those that do not include them. In both these approaches, aggregation of the observations to sample plots has usually been taken into account through random effects, but this has not always been done. We will discuss alternative model formulations for H-D models and report an extensive comparison of 16 nonlinear functions in this context using a total of 28 datasets. Suggestions on model selection, model fitting procedures, prediction and data collection are given from the point of view of large-scale inventories such as the national forest inventories.

Materials and methods: The datasets represent a wide range of tree species, regions, and ecological zones, consisting of about 126 000 measured trees from 3717 sample plots. The models are formulated as nonlinear mixed-effects and fixed-effects models.

Results: No uniformly best function, model formulation, or model fitting procedure was found. However, a 2-parameter Näslund and Curtis function provided satisfactory fit in most datasets for the plot-specific H–D relationship. Simple H-D model including tree diameter as the only predictor is not a properly formulated model in terms of distribution of random effects. Even though, it can be successfully used for prediction for plots where height measurements are available for prediction of random effects, it may give very unrealistic predictions for plots without calibration measurements. A well-fitting model includes some plot-specific aggregates of tree diameters as predictors, measurement of which does not require additional information then tree diameters. Model fitting and height imputation procedures developed for this study are provided in an R-package for practical use in inventories. They are currently used e.g. in FAO's Open Foris software.

Conclusion: Mixed-effect models with plot-specific calibration using random effects are a perfect tool for imputation of tree heights in a forest inventory. The Näslund's and Curtis functions are good two-parameter functions for the relationship. R-package lmfor includes easy-to-use functions for imputation in practical local to national forest inventories.

References:

Lappi, J., Mehtätalo, L. and Korhonen, K.T. 2006. Generalizing sample tree information. in Kangas, A. and Maltamo, M (editors) Forest inventory - methodology & applications. Springer

Mehtätalo, L., de-Miguel, S., and Gregoire, T.G. 2015. Modeling height-diameter curves for prediction. Canadian Journal of Forest Research, 45(7): 826-837, 10.1139/cjfr-2015-0054.

1. University of Eastern Finland, School of Computing, P.O.Box 111, 80101 Joensuu, Finland. e-mail lauri.mehtatalo@uef.fi 2. Yale University, School of Forestry and Environmental Studies
360 Prospect Street New Haven, CT 06511-2189 3. Department of Crop and Forest Science, University of Lleida-Agrotecnio Center (UdL-Agrotecnio), Av. Rovira Roure, 191, E-25198, Lleida, Spain