remote sensing

MDPI

Reply

Reply to Vauhkonen: Comment on Tompalski et al. Combining Multi-Date Airborne Laser Scanning and Digital Aerial Photogrammetric Data for Forest Growth and Yield Modelling. *Remote Sens.* 2018, *10*, 347

Piotr Tompalski [1,*], Nicholas C. Coops [1], Peter L. Marshall [1], Joanne C. White [2], Michael A. Wulder [2] and Todd Bailey [3]

1 Faculty of Forestry, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada; nicholas.coops@ubc.ca (N.C.C.); peter.marshall@ubc.ca (P.L.M.)
2 Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, 506 West Burnside Road, Victoria, BC V8Z 1M5, Canada; joanne.white@canada.ca (J.C.W.); mike.wulder@canada.ca (M.A.W.)
3 West Fraser–Slave Lake, P.O. Box 1790, Slave Lake, Alberta, AB T0G 2A0, Canada; todd.bailey@westfraser.com
* Correspondence: piotr.tompalski@ubc.ca

Received: 28 August 2018; Accepted: 5 September 2018; Published: 8 September 2018

Linking Airborne Laser Scanning (ALS) area-based approaches (ABA) to estimate forest inventory attributes to growth and yield models is an important prerequisite to more fully integrating this technology into forest inventory. In our recent papers [1,2], we developed and demonstrated a method that allows ABA predictions of forest inventory attributes at a grid cell level, to be integrated into growth and yield models. In our initial work [1], we presented a template-matching approach that was based on area-based forest inventory attributes (maximum height, Lorey's height, quadratic mean diameter, volume) derived from a single date of ALS data, and a database of yield curves generated with an existing, operational stand-level growth and yield model. In [2] we built-upon this work and demonstrated how the template matching approach can be used with area-based attribute estimates derived for two points in time from two different point cloud acquisitions. The developed method is innovative, and offers one potential approach to integrating ALS-derived estimates into growth and yield models. Our aims in [2], were clearly defined—we analyzed (i) how the accuracy of cell-level yield projections changed depending on whether single or multiple area-based outputs were used during curve assignment, and (ii) what were the main drivers of the yield curve matching error. We kept the approach generic, linking to an established and relevant Canadian growth model, but highlighted that the approach was not dependent on any one growth model and rather, could be modified and implemented elsewhere as needed. We framed the work in a manner that enables others to apply the approach with a similar or preferred growth model to test its broad applicability and usefulness.

Vauhkonen's comment to our paper recognizes that this area of research is important and that there are many approaches and points of view regarding how best to link ALS area-based estimates with growth and yield models. We appreciate his interrogation of the approach and demonstration of when—under certain conditions—the method may not select the optimum growth and yield curve. We remain confident that our advice in the paper to examine the error components of each of the original ABA models is sound and is the most logical way to assess if the curve selection for a certain cell is valid. We likewise believe this approach, as proposed, is an innovative solution to linking

area-based estimates of forest attributes to growth and yield models and are pleased that this work is generating debate and potential refinements.

In his comment, Vauhkonen focuses principally on the details related to the particular growth model used in our study (GYPSY), and provides examples of how, under different scenarios, the template matching approach would result in unreasonable projections of stand attributes. As stated above, we agree with Vauhkonen, that in some cases the template matching method may result in the selection of a non-optimum yield curve and in [2] we provided a measure of discrepancy between candidate curves ("uncertainty") that could inform on such situations. We also indicated that further work was needed to analyze in more detail and from different perspectives how the proposed method can be improved or made more applicable outside of a given study area or research context.

The scope of our paper, as clearly stated in the introduction, was to take an existing well-established and operational growth model and link it to area-based attribute estimates at two points in time. This is the situation many users of ALS data will likely face in the near future. Developing new growth models or intensive model simulations of growth and yield models currently used by management is not likely to be within the scope of most forest inventory practitioners, rather linking to existing models is the most likely scenario. We therefore utilized GYPSY as it was designed to be used, and focused on differences between using a single set of area-based estimates or two datasets with two area-based estimates representing two points in time. This objective allowed us to focus on the unique contribution of our study: integrating growth simulators with area-based estimates representing two points in time.

Vauhkonen questions the overall utility of using multiple area-based forest inventory attributes to assign yield curves to cells, arguing that existing growth and yield models are designed to operate with limited input information. This represents a philosophical rather than a scientific viewpoint and is one to which we do not subscribe. As ALS is a proven technology for predicting multiple forestry inventory attributes, why limit the lines of evidence that are used to select the best growth curve? Template matching provides the opportunity to use multiple stand attributes to select the optimal curve for each grid cell, and more importantly can be used with area-based estimates for multiple points in time. The latter is especially important when repeated cell-level inventories are available, which will be more common as ALS data are routinely acquired by the forest sector. Simple error checks to ensure the selected curve is valid can be implemented as logical developments towards an operational implementation. It is relatively straightforward to simulate how an existing approach may break down; it is more difficult to develop innovative approaches that users are well positioned to adapt and apply to their own unique situation. We stand behind our research methods, implementation, and related outcomes and look forward to making further refinements as well as seeing possible community adaptation and uptake.

Author Contributions: The authors contributed equally to the overall research design, approach, and analysis of the original paper as well as this response

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tompalski, P.; Coops, N.; White, J.; Wulder, M. Enhancing Forest Growth and Yield Predictions with Airborne Laser Scanning Data: Increasing Spatial Detail and Optimizing Yield Curve Selection through Template Matching. *Forests* **2016**, *7*, 255. [CrossRef]
2. Tompalski, P.; Coops, N.C.; Marshall, P.L.; White, J.C.; Wulder, M.A.; Bailey, T. Combining multi-date airborne laser scanning and digital aerial photogrammetric data for forest growth and yield modelling. *Remote Sens.* **2018**, *10*, 347. [CrossRef]