Editorial

Operationalization of Remote Sensing Solutions for Sustainable Forest Management

Gintautas Mozgeris 1,* and Ivan Balenović 2

1 Vytautas Magnus University, K. Donelaičio str. 58, LT-44248 Kaunas, Lithuania
2 Croatian Forest Research Institute, Division for Forest Management and Forestry Economics, Trnjanska cesta 35, HR-10000 Zagreb, Croatia; ivanb@sumins.hr
* Correspondence: gintautas.mozgeris@vdu.lt; Tel.: +370-37-752-291

The pre-requisite for sustainable management of natural resources is the availability of timely, cost-effective, and comprehensive information on the status and development trends of the management object. An essential source of such information has always been the application of remote sensing. Data and algorithms to use remote sensing in forestry are discussed in numerous texts. Nevertheless, the level of operationalization of research results needs to be either improved or further tested. On the other hand, remote sensing researchers are often aimed at purely academic objectives, thus lacking support and guidance from practical forestry, which does influence the quality of scientific exercises. Thus, science-driven solutions for knowledge transfer between researchers and stakeholders/policy makers/end-users are becoming increasingly important.

This Special Issue aimed to compile research papers dealing both with methodologies of remote sensing and implementation of research results to facilitate sustainable forest management. The focus was on the development of algorithms for the characterization of forest and forestry; however, with the emphasis also on the operationalization of remote sensing for natural resource management through the integration of scientific research and its practical utilization. Even though all authors identified further research needs, some of their developments had already been implemented or were ready for operational use. Altogether, there were 13 papers published in this Special Issue. The studies were implemented in three continents, using multiple remote sensing platforms, ranging from mobile laser scanning (MLS) devices or unmanned aerial vehicle (UAV) and airborne laser scanning (ALS) systems up to various satellite systems. Among the methods to process the remotely sensed data, the increasing focus on machine learning algorithms should be mentioned. Table 1 summarizes the key message of all published papers. More detailed information on the individual articles published in this Special Issue is given below in alphabetical order according to the name of the first author.

Deur et al. [1] introduced a study aiming to identify three deciduous tree species in a relatively very complex deciduous forest utilizing information available from conventional multispectral satellite imagery (WorldView-3). Two machine learning algorithms were tested—random forest and support vector machine, with the first method resulting in relatively better performance. High overall classification accuracy (85%) was reported using spectral satellite image characteristics only as the input. The authors managed to improve the accuracy of classification by introducing textural features from the satellite imagery and using them in combination with the spectral ones.
| Reference          | Region of Study                      | Remote Sensing Data/Equipment                                      | Focus of Study                                                                 | Implementation Status                       |
|--------------------|--------------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------|
| Deur et al. [1]    | Croatia                              | WorldView-3                                                         | Classification of deciduous tree species using machine learning algorithms      | Further research needed                    |
| Duarte et al. [2]  | Portugal                             | eBee SenseFly drone with a Parrot SEQUOIA camera                   | Detection of pest-introduced damages using multispectral images acquired from unmanned aerial vehicle (UAV) and a variety of image processing approaches | Partly ready for operational use, some aspects need further research |
| Fernandez-Carrillo et al. [3] | Europe | Multiple satellite data                                               | Development of a protocol to validate remote sensing derived forest/non-forest classification maps across Europe | Approach ready for operational use, some aspects need further research |
| Fernandez-Carrillo et al. [4] | Czech Republic | Sentinel-2                                                          | Development of methodology for automated bark beetle damage mapping using satellite images | Further research needed                    |
| Hawryło et al. [5] | Poland                               | Landsat 7 and airborne laser scanning (ALS) data                   | Predicting growing stock volume using remotely sensed data and ground reference data from National Forest Inventories (NFIs) with uncertain georeferencing accuracies | Approach ready for operational use under some conditions, some aspects need further research |
| Janiec et al. [6]  | Republic of Sakha, Russian Federation| Multiple satellite, geographic information systems (GIS) and bioclimatic data | Modelling the forest fire risk using multiple predictors as an option for automated fire management system | Approach ready for operational use, some aspects need further research |
| Kweon et al. [7]   | Republic of Korea                    | Mobile laser scanning (MLS) device                                  | Evaluating the use of an MLS device mounted on a vehicle for forest road inventories | Approach ready for operational use, some aspects need further research |
| Löw et al. [8]     | Austria                              | Sentinel-2                                                          | Time series analysis (TSA) framework for phenology modelling and forest disturbance mapping | Approach ready for operational use          |
| Obata et al. [9]   | Georgia, United States of America    | Landsat                                                             | Predicting growing stock volume using Landsat time series and publicly available ancillary information | Approach ready for operational use, some aspects need further research |
| Pilaš et al. [10]  | Croatia                              | Sentinel-2 and DJI INSPIRE 2 drone with a ZENMUSE X5S camera       | Bi-sensor approach to map gaps in forest canopy                                 | Approach ready for operational use          |
| Rocha et al. [11]  | Portugal                             | Synthetic aperture radar (SAR), global positioning systems (GPS), and ALS | What should be the resolution of digital elevation models for eco-hydrological simulations | Approach ready for operational use, some aspects need further research |
| Sakti et al. [12]  | Southeast Asia                       | Multiple satellite and derived data                                | The role of remote sensing data products to investigate the drivers behind degradation of mangroves in Southeast Asia | Approach ready for operational use, some aspects need further research |
| Syahid et al. [13] | Southeast Asia                       | Multiple satellite and derived data                                | Mapping the land suitability for mangrove restoration using remote sensing under different climate scenarios | Approach ready for operational use, some aspects need further research |
Detection and quantification of damages by Eucalyptus Longhorned Borers in eucalyptus stands using widely available UAV-based equipment was investigated in a study by Duarte et al. [2]. They used five spectral indices and nonparametric Otsu thresholding analysis to identify the damage. Individual treetops were detected using local maxima filtering; the crowns were extracted using large-scale mean-shift segmentation and then they were classified using random forest algorithm, resulting in a very high overall classification accuracy (98.5%). Finally, classified crowns were used to elaborate on the forest density maps. The findings were discussed as having high importance for forest practitioners, as they could support full area surveys and timely identification of the most critical hotspots of damaged trees.

Fernandez-Carrillo et al. [3] presented a validation methodology to evaluate remote sensing-based products under conditions, when homogeneous field reference data sets were available. Their approach was based on using stratified random and the development of a reference data set based on independent visual interpretation of satellite images. The approach was checked testing the accuracy of forest masks derived for 16 test sites in six European countries (Spain, Portugal, France, Croatia, Czech Republic, and Lithuania) using Sentinel-2 images. The overall forest/not-forest classification accuracies ranged from 76 to 96.3%. The checks were then discussed with external local forestry stakeholders. To facilitate the application of remote sensing in operational forestry, the authors suggested to consider a creation of unified reference data sets at continental or global scales.

Sentinel-2 images were tested to map bark beetle damages by Fernandez-Carrillo et al. [4]. Classification accuracies over 80% were yielded using multi-temporal regression models to detect and map the severity of pest outbreaks in spruce forests. Suggesting their approach for operational use and underlining the cost-effectiveness and ability to derive forest vitality maps on a regular base, the authors, however, accepted further research needs aimed at early detection and forecasting of the outbreaks.

The issue raised by Hawryło et al. [5] could be used to explain the limited use of remotely sensed data in operational National Forest Inventories (NFIs) in many countries. That is, the NFIs often lack accurately georeferenced field plots. The authors tested the performance of prediction algorithms (multiple linear regression, k-nearest neighbours, random forest, and deep learning fully connected neural network) to estimate the growing stock volume using Landsat 7 and ALS data with the Polish NFI sample plots as the ground reference. The positional errors of the NFI plots could be in the order of several to about 15 m. Nevertheless, the possibility to achieve desirable outputs was proven in coniferous forests with a high number of NFI plots. Landsat-derived predictors did not increase much the accuracies of growing stock volume predictions if used together with ALS data. Moreover, the deep learning algorithm did not outperform other more traditional approaches under the conditions of the conducted experiments.

Janiec et al. [6] evaluated the impacts of various factors on fire occurrence in North-Eastern Siberia. Then, they tested two machine learning algorithms (maximum entropy and random forest) to estimate the forest fire risks using satellite images (Landsat TM, Modis TERRA, GMTED2010, VIIRS) as well as geographic and bioclimatic data. They also suggested the key role of remote sensing in operational forest fire monitoring and management system.

Kweon et al. [7] evaluated the accuracy and efficiency aspects of using Trimble MX2 MLS device mounted on a vehicle to produce 3D maps within the frames of forest road inventories. They also compared the performance of MLS against the solutions based on surveys using the global navigation satellite system and total station. The key finding was that forest roads could be mapped using MLS device at precision levels suitable to produce high resolution 3D maps.

A novel time series analysis approach based on Sentinel-2 data and a dynamic Savitzky–Golay phenology modelling algorithm was presented by Löw et al. [8]. They proposed a ready for operational use solution for forest monitoring with functionality to locate and date forest disturbances. The key points of their approach were the modelling
phenology courses using Sentinel-2 time series; calculating of several vegetation indices and detecting deviations from the modelled phenology courses to be associated with forest disturbances; and, finally, producing the forest phenology and disturbance maps.

Obata et al. [9] introduced forest growing stock estimation solution using long Landsat time series and two ancillary data bases on land covers and disturbances, available for USA. They also tackled the well-known problem in application of satellite remote sensing in forest inventories—bias in large and small volume classes. The data of Forest Inventory and Analysis (FIA) unit field inventory measurements were used as the ground reference. Random forest algorithm was applied for the predictions. The authors managed to improve the prediction accuracies by employing the Landsat time series; however, incorporation of ancillary spatial data did not improve the estimations. The authors suggested to use their approach for volume estimations at sub-county level.

Pilaš et al. [10] demonstrated a novel approach to map the openings in forest canopy using information from two sensors and machine learning algorithms. They considered the UAV images as a potential source of ground truth and took the advantages of Sentinel-2 as a source of information for mapping over large areas. The authors explored various approaches to improve the predictive performance, like testing the use of single versus multi date satellite images, several vegetation and biophysical indices and textural features as predictors, and eight processing algorithms. Their main finding was that, by combining data from two sensors, the limitations of each sensor, namely, the coarser Sentinel-2 spatial resolution and limited flying range of the UAV, were minimized.

Rocha et al. [11] questioned the spatial resolution of digital elevation models (DEM) developed using synthetic aperture radar (SAR) interferometric data, global positioning systems (GPS)-based surveys, and ALS data. The key finding was that the finer resolution DEMs improved the performance of the soil and water assessment tool.

Two studies dealt with facilitating the management of mangroves using remote sensing and modelling tools. Sakti et al. [12] used multi-source remote sensing data products together with derived land cover, geophysical, climatic, and vegetation data to evaluate the factors leading to degradation of mangroves in Southeast Asia. They concluded that the predominant factors of mangrove degradation were agriculture and fisheries. Remote sensing was suggested as a powerful tool in evidence-based policy making.

Syahid at al. [13] introduced a land suitability map for mangrove plantations in Southeast Asia assuming different climate scenarios. They used an analytical hierarchy process with remote sensing, geomorphological, hydrodynamic, climatic, and socio-economic data to assess the lands suitable for mangrove restoration. They suggested the availability of near 400,000 ha of land in Southeast Asia suitable for mangrove planting with Indonesia accounting for the largest share.

All the above-mentioned studies confirmed the great potential of various remote sensing technologies for operational use in sustainable forest management. We hope that the obtained results and findings will encourage further research and convince forestry practitioners of the importance and benefits of better integration of remote sensing in operational forestry.

Author Contributions: Conceptualization, G.M. and I.B.; Writing—original draft, G.M.; Writing—review & editing, I.B. All authors have read and agreed to the published version of the manuscript.

Funding: This Special Issue is partly linked with the MySustainableForest project, which has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 776045.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request.

Acknowledgments: As the Guest Editors we would like to thank all the authors who accepted the challenge to share their research results and ideas in this Special Issue. Special thanks to the reviewers,
who were anonymous to the authors, but not to us—it was amazing how much you helped the authors to improve their manuscripts. Thanks to the editorial staff of Remote Sensing for igniting the idea and support to have it “operationally implemented”. Thanks to MySustainableForest people for helping to spread the message and pressing to publish.

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

References

1. Deur, M.; Gašparović, M.; Balenović, I. Tree Species Classification in Mixed Deciduous Forests Using Very High Spatial Resolution Satellite Imagery and Machine Learning Methods. Remote. Sens. 2020, 12, 3926. [CrossRef]
2. Duarte, A.; Acevedo-Muñoz, L.; Gonçalves, C.; Mota, L.; Sarmento, A.; Silva, M.; Fabres, S.; Borralho, N.M.; Valente, C. Detection of Longhorned Borer Attack and Assessment in Eucalyptus Plantations Using UAV Imagery. Remote. Sens. 2020, 12, 3153. [CrossRef]
3. Fernandez-Carrillo, A.; Franco-Nieto, A.; Pinto-Bañuls, E.; Basarte-Mena, M.; Revilla-Romero, B. Designing a Validation Protocol for Remote Sensing Based Operational Forest Masks Applications: Comparison of Products Across Europe. Remote. Sens. 2020, 12, 3159. [CrossRef]
4. Fernandez-Carrillo, A.; Patočka, Z.; Dobrovolný, L.; Franco-Nieto, A.; Revilla-Romero, B. Monitoring Bark Beetle Forest Damage in Central Europe A Remote Sensing Approach Validated with Field Data. Remote. Sens. 2020, 12, 3634. [CrossRef]
5. Hawrylo, P.; Francini, S.; Chirici, G.; Giannetti, F.; Parkitna, K.; Krok, G.; Mitelsztedt, K.; Łisianczuk, M.; Stereńczak, K.; Ciesielski, M.; et al. The Use of Remotely Sensed Data and Polish NFI Plots for Prediction of Growing Stock Volume Using Different Predictive Methods. Remote. Sens. 2020, 12, 3331. [CrossRef]
6. Janiec, P.; Gadal, S. A Comparison of Two Machine Learning Classification Methods for Remote Sensing Predictive Modeling of the Forest Fire in the North-Eastern Siberia. Remote. Sens. 2020, 12, 4157. [CrossRef]
7. Kweon, H.; Seo, J.I.; Lee, J.-W. Assessing the Applicability of Mobile Laser Scanning for Mapping Forest Roads in the Republic of Korea. Remote. Sens. 2020, 12, 1502. [CrossRef]
8. Löw, M.; Koukal, T. Phenology Modelling and Forest Disturbance Mapping with Sentinel-2 Time Series in Austria. Remote. Sens. 2020, 12, 4191. [CrossRef]
9. Obata, S.; Cieszewski, C.J.; Iii, R.; Bettinger, P. Random Forest Regression Model for Estimation of the Growing Stock Volumes in Georgia, USA, Using Dense Landsat Time Series and FIA Dataset. Remote. Sens. 2021, 13, 218. [CrossRef]
10. Pilaš, I.; Gašparović, M.; Novkinić, A.; Klobučar, D. Mapping of the Canopy Openings in Mixed Beech–Fir Forest at Sentinel-2 Subpixel Level Using UAV and Machine Learning Approach. Remote. Sens. 2020, 12, 3925. [CrossRef]
11. Rocha, J.; Duarte, A.; Silva, M.; Fabres, S.; Vasques, J.; Revilla-Romero, B.; Quintela, A. The Importance of High Resolution Digital Elevation Models for Improved Hydrological Simulations of a Mediterranean Forested Catchment. Remote. Sens. 2020, 12, 3287. [CrossRef]
12. Sakti, A.D.; Fauzi, A.; Wilwatikta, F.N.; Rajagukguk, Y.S.; Sudhana, S.A.; Yayusman, L.F.; Syahid, L.N.; Sritarapipat, T.; Principe, J.; Trang, N.T.Q.; et al. Multi-Source Remote Sensing Data Product Analysis: Investigating Anthropogenic and Naturogenic Impacts on Mangroves in Southeast Asia. Remote. Sens. 2020, 12, 2720. [CrossRef]
13. Syahid, L.N.; Sakti, A.D.; Virtriana, R.; Wikantika, K.; Windupranata, W.; Tsuyuki, S.; Caraka, R.E.; Pribadi, R. Determining Optimal Location for Mangrove Planting Using Remote Sensing and Climate Model Projection in Southeast Asia. Remote. Sens. 2020, 12, 3734. [CrossRef]