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| **Imaging spectroscopy for bark beetle detection in Norway spruce and the relevance of the red-edge spectral range** |
| In this study, hyperspectral data of two geographically distant study areas in Germany were analyzed to find the most effective spectral wavelengths for red-edge-based vegetation indices to differentiate bark beetle-infested Norway spruce into three infestation classes, including green-attack. Considering that the relationship between red-edge position (REP) and reflection shoulder position (RESP) is crucial for the relative quantification of chlorophyll concentration and LAI and their changes due to bark beetle infestation, we tested normalized difference red-edge indices (NDRE) formed from these parameters. Using the second derivative method, the REP calculation resulted in an average value of the infestation classes of 715.14 nm and 715.81 nm (both corresponding with the 716 nm band of the camera) for the two independent study sites, the RESP wavelengths were 759.35 nm (camera band 758 nm) and 760.4 nm (camera band 761 nm), respectively. Furthermore, using combinations of 75 spectral bands in the range 685 nm to 850 nm, we formed and analyzed 1187 different NDREs, and two additional vegetation indices, and show that the sorted, normalized Kruskal-Wallis H-value, followed by a frequency analysis of the RESP and REP bands of the 10% of the highest ranked NDREs is an effective way to identify the global optima of these parameters. The optimal REP and RESP estimated using this approach were determined at 714 nm and 758 nm, respectively. The derived normalized difference red-edge index NDRE758\_714 could be successfully applied to both test sites. Moreover, we found that aggregating hyperspectral bands into broader bands - 703 nm to 729 nm for a REP band and 741 nm to 767 nm for a RESP band - did not degrade model accuracy when used in a multispectral NDRE, suggesting that a hyperspectral camera is not required to perform the task. Multinomial logistic regression (MNLR) and random forest (RF) classification models were successfully transferred between the two geographically distant study sites. The predictive accuracies of the models for the test data indicated MNLR to be more robust than the RF. With the MLNR models applied, overall accuracies 77.4 % were achieved in the first study area imaged during the green-attack core period, and 88.5 % in the second study area imaged at the final green-attack stage. Our results contribute to forest health monitoring with imaging spectroscopy data and provide practical recommendations for sensor design with broader bands. |

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