Abstract

Epidemic (calamitous) overpopulations of bark beetles *(Scolytinae Latreille, 1804)* caused by climate change and inappropriate tree species composition currently have the most negative impacts on the development of Europe's mixed and boreal forests. Epidemic overpopulations can significantly undermine forest health and cause economic losses. It is therefore essential to use appropriate methods for early detection of bark beetle disturbance. Multispectral remote sensing (RS) methods using unmanned aerial systems (UAS) represent a new option for contactless landscape monitoring providing quantitative information on vegetation health with high spatiotemporal resolution and therefore appear to be suitable for early detection of disturbance. The thesis focused on the validation of the use of UAS multispectral photogrammetry and image classification methods for the detection of individual forest disturbance stages caused by the spruce bark beetle *(Ips typographus Linnaeus, 1758)* at the level of individual trees for the study of disturbance dynamics. In this dissertation, all important aspects of detection were elaborated: analysis of the suitability of spectral bands for disturbance detection, radiometric calibration of multispectral cameras, automated segmentation of individual canopies from photogrammetric point cloud (PPC) and classification of disturbance stages at individual tree level using convolutional neural networks (CNN) from the multispectral orthophoto. Vegetation stress caused by spruce bark beetle is best detected in spectral bands reflecting changes in chlorophyll content due to disruption of the vascular bundles. This corresponds to the red (650 nm), red-edge (700 nm) and NIR (800 nm) part of the spectrum of the multispectral cameras and vegetation indices calculated from these bands. In case of using CNN classifiers, it is recommended to use RGB, red-edge or NIR bands without vegetation indices. Automatic methods of canopy segmentation from PPC can be a substitute for time-consuming manual canopy segmentation from the orthophoto for infestation stage classification of individual trees while maintaining an ideal point density (~20–60 points/m^2, minimum 10 points/m^2). Lower or higher point cloud densities lead to reduced segmentation accuracy. The best CNN classification models were able to detect individual disturbance phases including the green attack stage resulting in the accuracy around 80% without using time series imagery. The UAS multispectral photogrammetry methods featuring the CNN classifiers are therefore fully applicable to the detection of forest disturbance and its dynamics, filling the scaling gap between field surveys and aerial RS, because once a reference set has been collected, they allow automated detection of disturbance phases of larger forest units at the individual tree level. Therefore, these methods can be used not only for basic identification of infested trees and early elimination, but also for monitoring the dynamics of bark beetle disturbance, detecting hotspots, predicting spread, and understanding recent changes in disturbance regimes due to climate change.

Keywords: forest disturbance; Ips typographus; multispectral photogrammetry; unmanned aerial systems; individual tree-based classification; convolutional neural networks