Remote Sensing in Assessment of Forest Dieback and in Regeneration Processes

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Abstract − Long-term and lasting human interference in forest ecosystems, together with changing climatic conditions in Central European mountain forests have resulted in the loss of equilibrium mechanisms and a resulting increase in susceptibility to ecological disturbances. As a result, Norway spruce forests have been subject to frequent bark beetle outbreaks since the 1990's. We report on two methods for estimating bark beetle outbreaks and regeneration process in spruce forests: analysis of Landsat satellite data to quantify the spatial distribution of forest decline under bark beetle outbreaks between 1985-2002; and an assessment of forest regeneration and recovery process from recent airborne hyperspectral, color IR and LiDAR data, and botanical surveys in sites that have undergone different forest management practices during and after forest decline. The results document a significant increase in the area of highly damaged and dead forest classes, from 1% in 1985 to 16% in 1998, and a decrease in the area of healthy and moderately damaged spruce classes from 73% in 1985 to 52% in 1998. Since 1998 tree decline has continued but regeneration has started. We find differences between plant species richness and trajectory of the regeneration process for forests with and without interventions.

Keywords: hyperspectral, lidar, bark beetle, forest, ecosystems

1. INTRODUCTION

Since 1990's, Central European mountain spruce forests have been facing to frequent bark beetle (*Ips typographus* (L.)) outbreaks which, together with storm events are the most important natural disturbances determining the dynamics of the forests (Korpel, 1995; Schelhaas et al., 2003).

The frequency of bark beetle outbreaks may be increasing due to decreased resistance of the forests due to the previous forest management practices (evenly-aged Norway spruce monocultures) and changing climate: warmer and longer summers supporting faster and more frequent bark beetle outbreaks/propagation; more frequent and severe wind storms resulting in extensive areas of uproots (Ayres and Lombardero, 1999; Schelhaas et al., 2003).

A large complex of mountain spruce forests situated in the central Europe was affected by a bark beetle outbreak in the 1990's (Zemek and Heřman, 2001, Zemek et al. 2003). Moreover, a conflict exists between the interests of nature conservancy and those who favor using the traditional forestry approach to combat bark beetle mainly by salvage logging (Furlong, 2006). Results describing natural regeneration of tree species in selected small-scale plots have already been published (Jonášová and Prach, 2004; Jonášová and Prach, 2008). But more evidence in a large spatial scale and environmental context is necessary to get unbiased information about the trajectories of the regeneration processes in sites where different approaches were applied to support management during future bark beetle attacks. For this purpose satellite multispectral, airborne hyperspectral, LiDAR data and GIS modeling is being used.

The overall aim is to test this hypothesis: Plant species richness and the trajectory of the regeneration process are different between forests with and without interventions (e.g. salvage logging). Two basic approaches have been adopted to meet the aim:

1. Retrospective analysis of spatial distribution of forest decline under bark beetle outbreaks (BBO) from satellite multispectral and ancillary data from 1990's
2. Assessment of forest regeneration/recovery process in sites which undergone different forest management practices during/after BBO from acquired airborne hyperspectral, LiDAR data and botanical survey.

2. DATA AND METHODS

The study area is in Middle Europe, a part of Bohemian Forest (Sumava Mts.). It includes the Sumava and Bavarian National Parks and is formed by a large mountain forested range shared by three countries, namely the Czech Republic, Germany, and Austria (Fig. 1).
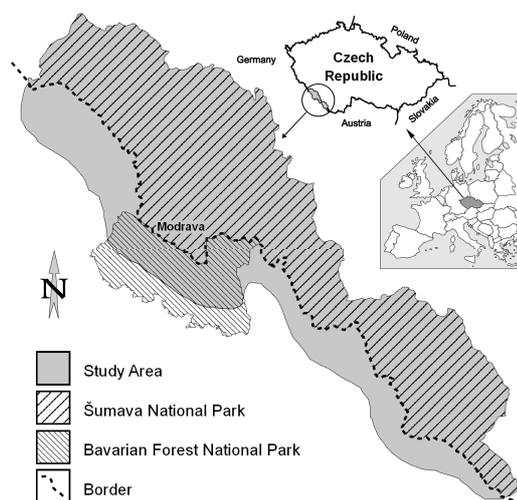
Figure 1. Situation of the study area

2.1 Classification of Landsat Thematic Mapper Data
We extended the time series (1985-1998) of forest cover assessment (Zemek and Heřman, 2001) by carrying out a neural

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net supervised classification of Landsat7 ETM+ data (21/7/2002) with support of map/field data (cooperation with Administration of the Sumava National Park), and ancillary data (colour infrared aerial photos, DEM).

2.2 Analysis of Airborne Data

Three types of airborne imagery data and field monitoring data were used to assess forest recovery processes during/after the bark beetle attacks:

1) Hyperspectral (HS)
    a) AISA Eagle, 400-890 ηm, 10 ηm band step, 40 cm pixel size, acquired 2/8/2009
    b) AISA Dual Eagle, 400-2450 ηm, 5 ηm band step, 80 cm pixel size, acquired 1/9/2009
    c) Both data acquisitions supported by full field campaign (spectroradiometer ASD FieldSpec-3s, reflectance calibration panels NEXTEL, GPS – TOPCON, atmosphere parameters Sunphotometer
2) Colour infrared UltraCamX (CIR) - R,G,B,NIR, 20 cm pixel size, acquired 9/7/2010
3) LiDAR data – Leica ALS50-II, acquired 21/10/2010
4) Botanical survey of species abundance and their spatial distribution within 23 plots, each 20x20 m in size, have been monitoring regeneration processes since 1997

All HS data were postprocessed for radiometric (CaliGeo), atmospheric (ATCOR-4) and geometric (PARGE) calibrations. CIR data were orthorectified and LiDAR data postprocessed with TerraScan software.

2.3 HS and CIR Data Assessment

We used unsupervised classification of CIR data to identify patches of herbs represented by small areas and to distinguish dead lying trees. These results were used also as an input to train (together with plot monitoring data) supervised classifications, which were run on hyperspectral 40, and 80 cm. The later HS data we decorrelated before NN classification using PCA analysis for B, G, R, NIR, WNIR data sets, taking only the 3 main components into the classifications.

3. PRELIMINARY RESULTS

a) Classification of Landsat5 TM data 2002 displays significant regeneration processes in former treeless area compared with 1998 (Table 1.).

Table 1. Classification results from Landsat5 TM

Classes	Entire study area		Modrava region	
Year	1998	2002	1998	2002
Mixed and broad-leaved	24,9	24,2	30,9	39,2
Healthy and moderately damaged Norway spruce	51,3	68,3	21,6	28,8
Highly damaged and dead Norway spruce	15,8	2,9	38,7	12,5
Clear cuts and forest plantations	7,2	3,8	8,6	19,4
Unclassified	0,8	0,8	0,2	0,1

b) We get more accurate classification outputs from HS 40 cm data even if they do not cover WNIR bands which are sensitive to water. This data enabled us to distinguish both crowns of single young and old (surviving) trees, standing dead trees,

shadows from trees, and patches of dominant species in open areas (*Calamagrostis villosa, Vaccinium myrtillus*). However, it failed in mixed (complicated) plots where herbs were mixed with dead lying trees and small young trees. Because of the 80 cm pixel size classification of HS data did not accurately distinguish spruce trees from herbs.
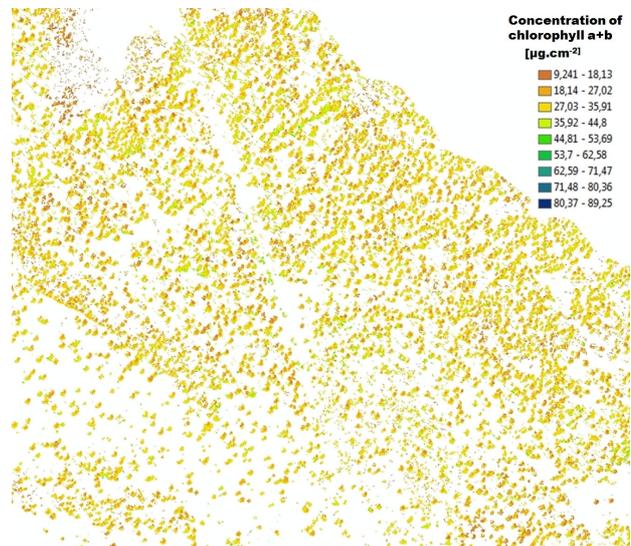
Figure 2. Chlorophyll a+b concentrations derived from 40 cm hyperspectral data.

Results of HS 40 cm data were used also to generate map of chlorophyll a+b contents for the sunlight parts of standing Norway spruce trees. We parameterized a 3D radiative transfer model for tree (DART) and leaf (PROSPECT), and simulated the bidirectional reflectance factor. Then by inverting the simulated database against acquired HS spectral reflectance data we got, after masking out shadows and "nontree" cover, concentrations of Ca+b (Fig. 2). The concentration ranged between 0-90 $\mu g.cm^{-2}$, reflecting also the low health status of most spruce trees in the region.

c) LiDAR ground returns were used to construct a Digital Terrain Model (DTM), which we then subtracted from a Digital Surface Model (DSM) that was constructed from the first returns.
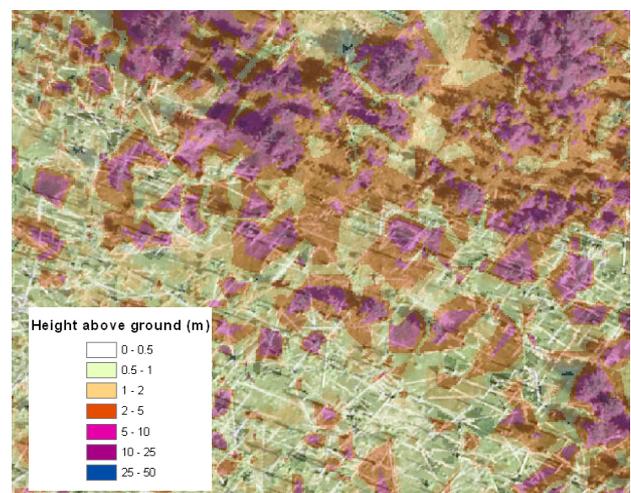
Figure 3. Vegetation height relative to forest floor, derived from LiDAR, shown as semi-transparent layer over R-G-B

image of trees, shadows, and fallen tree trunks interspersed with new growth.

This procedure yielded the height of the surface features above the ground. Figure 3 shows that the tops of surviving as well as standing dead trees are clearly identified. Shorter, new growth and low-lying shrubs are less reliably identified. Further work with the LiDAR data, including examining second returns in the DSM and applying object-oriented classification methods, is being carried out and will be reported on.

4.   CONCLUSIONS

We have presented preliminary results of a study employing hyperspectral, multispectral and LiDAR data sources to evaluate the regeneration process of a Norway spruce forest after bark beetle outbreak. The study extends a previous study for the same area, which was based only on Landsat multispectral data. The methods described here illustrate the ability to assess in greater detail the regeneration process. Further work will quantify the recovery process for areas having undergone different forest management processes following bark beetle outbreaks.

5.   REFERENCES

Ayres, M.P., Lombardero, M.J., 1999. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. *The Science of the Total Environment* **262**, 263-286.

Furlong, K, 2006. Unexpected narratives in conservation: Discourses of identity and place in Šumava National Park, Czech Republic. *Space and Polity* **10**, 47-65.

Jonášová, M., Prach, K., 2004. Central-European mountain spruce (*Picea abies* (L.) Karst.) forests: regeneration of tree species after a bark beetle outbreak. *Ecological Engineering* **23**, 15-27.

Jonášova, M., Prach, K., 2008. The influence of bark beetles outbreak vs. salvage logging on ground layer vegetation in Central European mountain spruce forests. *Biological Conservation* **141**, Issue 6, 1525-1535.

Korpel, S., 1995. Die Urwälder der Westkarpaten. Gustav Fischer Verlag, Stuttgart; Jena; New York

Schelhaas, M.J., Schuck, A., Varis, S., 2003. Database on Forest Disturbances in Europe (DFDE) – Technical Description. EFI Internal Report 14, pp. 44.

Zemek, F., Heřman, M., 2001. Bark beetle – A stress factor of spruce forests in the Bohemian Forest. *Ekologia-Bratislava* **20**, 95-107.

Zemek F., Cudlín P., Boháč J., Moravec I., Heřman M., 2003. Semi-natural Forested Landscape under a Bark Beetle Outbreak: a case study of the Bohemian Forest (Czech Republic). *Landscape Research* **28**, No. 3 ,279–292.