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Forest disturbance monitoring system based on high spatial resolution satellite images in the Kalkalpen National Park

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Abstract

Major storm events in many parts of Austria repeatedly led to the destruction of forest areas in recent years. Moreover, the windfall zones in conjunction with particularly very hot and dry summers provided ideal conditions for a progressive and continual infestation of spruce bark beetles. Therefore there is a strong need to support the estimation of forest disturbance in a cost-efficient manner. Remote sensing enables to extract valuable information to detect and analysis forest dynamics even from areas difficult to access.

The Kalkalpen National Park has initiated a pilot study together with the Interfaculty Department of Geoinformatics – Z_GIS (Salzburg University)to establish an operational framework for automated extraction of affected forest areas. Based on satellite imagery the analysis was complemented by available in-situ datahelp to identify area-effective by stressors such as storms and bark beetle attacks that result in deadwood. The spatial variability and dynamic of the forest ecosystem can be investigated and visualized. Data integration, data analyses and change detection were performed by an object-based image analysis (OBIA) methodology.

Keywords

Coarse woody debris;Object-based image analysis (OBIA);Change detection; Rapid Eye

Introduction

EO-based monitoring of forest disturbance

Major storm events in many parts of Austria led to the destruction of forest areas in recent years (e.g. Kyrill, January 2007; Paula, January 2008; Emma, March 2008). Moreover, the windfall zones in conjunction with given suitable environmental settings – particularly very hot and dry summers – provided ideal conditions for a progressive infestation of spruce bark beetles (*Ipstypographus*) over large regions. The beetle's population has exploded and the infestation of forests e.g. in the Austrian Kalkalpen National Park has continued. These forest disturbances triggered by abiotic (storm) and biotic (insect pests) factors result in a patchy distribution of coarse woody debris.

Nowadays scientific research emphasises the importanceof deadwood presencefor the health and functioning of a forest ecosystem at a variety of scales. Deadwood contributes positivelyto the nutrient cycling, long term storage for carbon dioxide as well as habitat provision in terms of ecological niches and biodiversity pools (LOUMAN et al. 2009; MÜLLER &BÜTLER 2010; RADU 2007). That's why in protected areas forest authorities require spatially explicitinformation on those deadwood areas and their changes over time to maintain forest management and conservation objectives and to contribute to habitat maintenance.

There is a strong need to support the estimation of forest disturbance on a regular and continuous basis in a cost-efficient and area-extensive manner. Here we focus on the potential of Earth observation (EO) to provide such information mainly from remote sensing data that also enable to detect forest change even from areas difficult to access.High resolution satellite imagery and reproducible methods for semi-automated feature extraction should support traditional techniques of large scale forest inventory through field surveys and aerial photo interpretation(DESCLÉE et al. 2006; WULDER et al. 2008; COOPS et al. 2010; MARX 2010;KOCH 2011).

The research conducted was part of a feasibility study initiated by the Kalkalpen National Park. The objective was to establish an operational framework to (semi)-automatically extract and monitor forest disturbances that result in coarse woody debris across an alpine forest habitat. Such a forest monitoring system should address the information needs of forest managers concerning their annual reporting tasks on the assessment of deadwood to the national forest authority. Specifically, the project aimed to examine the potential and limits of high spatial resolution multispectral remotely sensed data such as RapidEyeimagery with a ground resolution of up to 5m.

The approach should not only capture forest disturbances triggered in particular by storm events and insect pests for any given year, but also allow assessing and visualizing the spatial variability and dynamic of the forest ecosystem at regional scale. The role and performance of such an 'information service' is currently tested in a European (FP-7 SPACE) project called MS.MONINA (www.ms-monina.eu), which offers scale adaptive monitoring services for the implementation of the EU Habitats Directive.

Research objectives

Based on the objectives outlined above, the following research questions arise:

1. Is it possible to identify small-scale disturbances (as small groups of trees) within healthy forest stands?
2. Is multi-date RapidEye imagery a suitable data source for the detection of coarse woody debris caused by storm and bark beetle attacks in an alpine forest ecosystem?
3. What classification accuracy can be achieved for forest disturbance detection with (semi)-automated methods?

Data integration, data analyses and change detection were performed by an object-based image analysis (OBIA) methodology. The approach and the obtained results of this study are discussed in the following sections. A detailed validation of the extracted forest disturbances and the change assessment in cooperation with the national park authorities are still in progress.

Methods

Study area

The study area is situated in the Kalkalpen National Park in the federal country of Upper Austria, Austria.

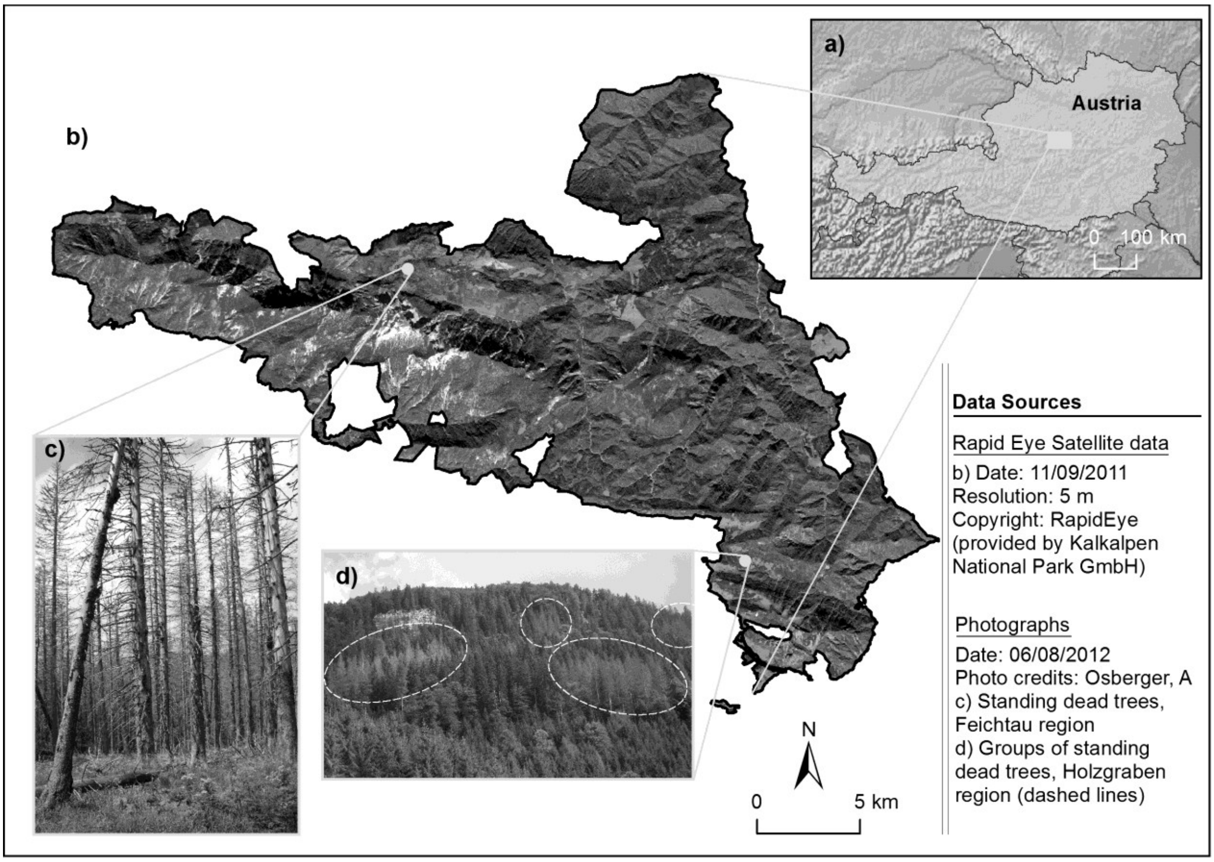

Figure 1: Kalkalpen National Park, Upper Austria

The national park covers an area of 208.5 km² andis Austria's largest closed protected forest area. Itwas established in 1997 and belongs tothe six national parks in Austria that are internationally recognized by the IUCN (International Union for the Conservation of Nature) under category II (national park). The regionisboth a European protected site in the network of NATURA 2000, according to the European Birds (79/409/EEC) and Habitats Directives (92/43/EEC), and a Ramsar site through the Ramsar Convention to protect wetlands due to the extended creek ecosystem in this area.

Forests represent four fifths of the national park area and are primarily allowed to develop naturally. The most common forest types are spruce-fir-beech forests. In recent years especially the Norway spruce stands (*Piceaabies*) faced progressive infestation of spruce bark beetles.

Data and pre-processing

Remotely sensed data

The decision to use RapidEye (www.rapideye.com)data for the annual forest monitoringwas based on the spatially and timely high coverage and the multispectral capacity.The RapidEye constellation includes five identical small satellites, which are calibrated equally one to another. They provide multispectral high-resolution imagery in five optical bands (440-850 nm). In addition to the visual bands and a near infrared (NIR) band, the sensor contains also the red-edge spectrum (690-730 nm), which is spectrally located between the Red and the NIR band without overlap. The corresponding part of theelectromagnetic spectrum is particularly sensitive for vegetation chlorophyll content because of the sudden increase of reflectance caused by vegetation.

Due to the high temporal and spatial coverage it was possible to acquire archived,radiometrically and geometrically corrected images of different years,covering the national park area nearly free of clouds or haze. The time series comprises three different dates t_1 = 19 Sept 2009, t_2 = 23 Aug 2010 and t_3 = 11 Sept 2011.The timing of the images in the late summer seasonal window is closely connected with the biologicalcycle of deciduous trees. In view of the fact that the process of discoloration of leaves and leaf fall starts in autumn, it is necessary to use images when forest vegetation is stable to distinguish properlycoarse woody debrisfrom vital trees. Then it is more likely that changes in spectral reflectance can be assigned to bark beetle attacks. The image data t_2 (RapidEye Level 1B) were orthorectified by combining a 10 m Digital Elevation Model (DEM) and precise ground control points (GCPs) selected from a set of digital orthophotosacquired in the years 2008 and 2009. Theorthorectified RapidEye scenet$_2$ served as the reference image to geo-correctdata t_1 and t_3 (RapidEye Level 3A) to minimise geometric offsets.

Auxiliary information

In addition to the remotely sensed imagery,silvicultural- and other geo-data, provided by the Kalkalpen National Park, were integrated in GIS vector formatto give useful input for the classification process. These included the topographic (e.g. bodies of water, avalanches), the vegetation (e.g. mountain pine stands, alpine pasture, grassland), the management (administrative boundaries) and the infrastructure (e.g. forest roads, paths) domain. With these layers we created a coarse forest mask to exclude non-forest areas for the subsequent change assessment. The reference data to evaluate the provided forest disturbance layer consists of deadwood areas (downed as well as standing dead trees) available as point and polygon features mapped by the national park authorities. Beyond taking these samples a detailed field validation in two small national park regions was carried out in August 2012.

Object-based image analysis for vegetation conditions

The advances in sensor technology along with the increasing spatial resolution of remote sensing data justify the object-based image analysismethodology for a spatially explicit and intelligent information extraction workflow (BLASCHKE 2010; LANG 2008). A shift has been recognized in the commonly accepted assumptions from discrete single pixels (picture element) as basic entities to meaningful spatially contiguous geographic image objectsas homogeneous regions by grouping neighbouring pixels. The feature space, beside spectral characteristics, is extended to make use of additional spatial (such as size, texture, shape, and neighbourhood), structural, hierarchical, and contextual information. The extended feature space in conjunction with a scaled object-hierarchycould be used to address the complexity of natural phenomena like forest ecosystemsin a more appropriate way (BLASCHKE &STROBL 2001; HAY et al. 2005; BLASCHKE 2010).

The method applied consists of two conjoined elements that aim at characterizing and classifying relevant changes (disturbances) in forest vegetation units. On the one hand, it is built on multi-scale image segmentation, partitioning the images into homogenous image objects on different scale levels.In addition, a class modelling approach – established as a rule-based system – is applied, which integrates expert knowledgeto modify and classify objects in the object-hierarchy based on the extended feature space (TIEDE et al. 2010; LANG 2008).

The method proposed for the alpine forest monitoring system consists of two main steps. An initial forest mask that reflects the current condition of the forest stands. In reference to this base layer forest change detection can be applied. The expert rule-sets for these two components were written within the eCognition object-based image analysis software framework (Trimble Geospatial Imaging). The modular programming language CNL (Cognition Network Language) allows the coding of rule-sets to address and process image objects in a vertical and horizontal hierarchy in a region-specific manner at any time in the rule-set(TIEDE et al. 2010).

Generating of a forest mask

The forest change detection needed as an initial step a forest/non-forest mask to exclude irrelevant features and focus the subsequent monitoring task only on forest stands. Furthermore all areas of forest disturbances had to be detected as well to represent the status quo on the amount of coarse woody debris before a specific year. Based on this status quo layer it is possible to calculate or recalculate the increase of deadwood on an annual base. Imaget$_2$of the satellite image series acted as base to perform an object-based forest/non-forest mask. Auxiliary datasets helped to better delineate both healthy forest stands and areas of forest disturbance in the year t_2. Non-forest objects mainly correspond to mountain pine stands, alpine pasture, grassland,water bodies, forest roads, debris, and rocks.

To address the complex natural appearance of forest stands and forest disturbance regarding the varying spectral response patterns fuzzy-based rules by means of membership functions were used. In addition the algorithm also focused on relational features as for instance the NDVI (Normalized Difference Vegetation Index) to differentiate between healthy forest stands and coarse woody debris. Such rules were mainly used to distinguish coarse woody debris from riversides, embankments and roadsides due to similar spectral values and from rock formations at a certain altitude. For the southern face of the Sensengebirge(western part of the national park; cf. Fig. 2) a specific refinement was necessary due to different vegetation composition and sparser vegetation in higher altitudes as compared to the rest of the national park area. For that region adjusted rulescould be applied within the same rule-set (region-based processing).Finally minor manual refinementwas performed to correct an insignificant amount of small objects that where wronglyassigned between the categories deadwood and rocks or debris due to spectral similarities.

Forest change detection

In order to identify forest disturbance areas in the images t_1 and t_3, a change detection approach was applied on the generated forest mask of image t_2. It focused primarily on the statistical analysis of the image objects avoiding therefore to some degree the dependence of atmospheric corrected imagery. For the object-specific change indication attime slott_1 mainly the normalisedNDVI per image objectwas used. The same algorithm for the change detection was applied on image t_3 enhanced through a combination of two additional feature characteristics (mean intensity value of the red band and absolute brightness to avoid confusions of forest disturbance and rock formations).

Results

The detected forest disturbances are provided in a GIS layer format for the national park authority.

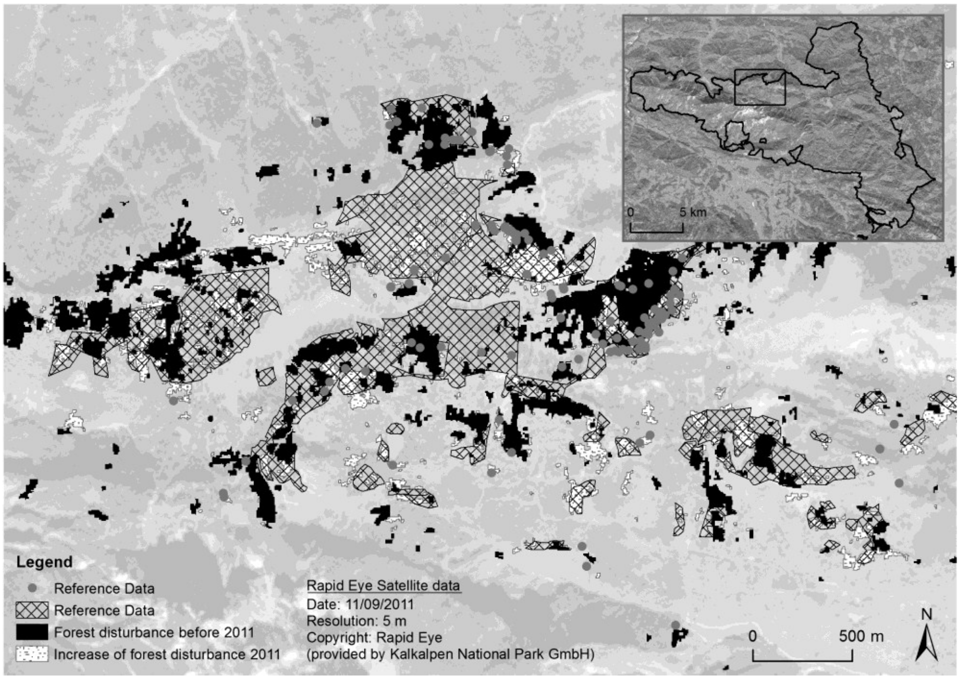

Figure 2: Forest disturbance up to 2011, Kalkalpen National Park

An initial statistical evaluation showed that the amount of deadwood extracted with the aid of remotely sensed data is about 5 to 15 % higher according to the respective reference year and region within the national park area. Reason for that is the detectionofeven fine-scaled forest disturbance areas within healthy forest stands. Also a more realistic analysis of canyons and steep slopes or in general of areas difficult to access was possible. Usually deadwood in areas difficult to access isestimated so far from the opposite hillsides only (if no recent aerial imagery is available). Primary preliminary validation with the existing reference data shows that the pattern of the forest disturbance matches quite well the pattern of the reference data.

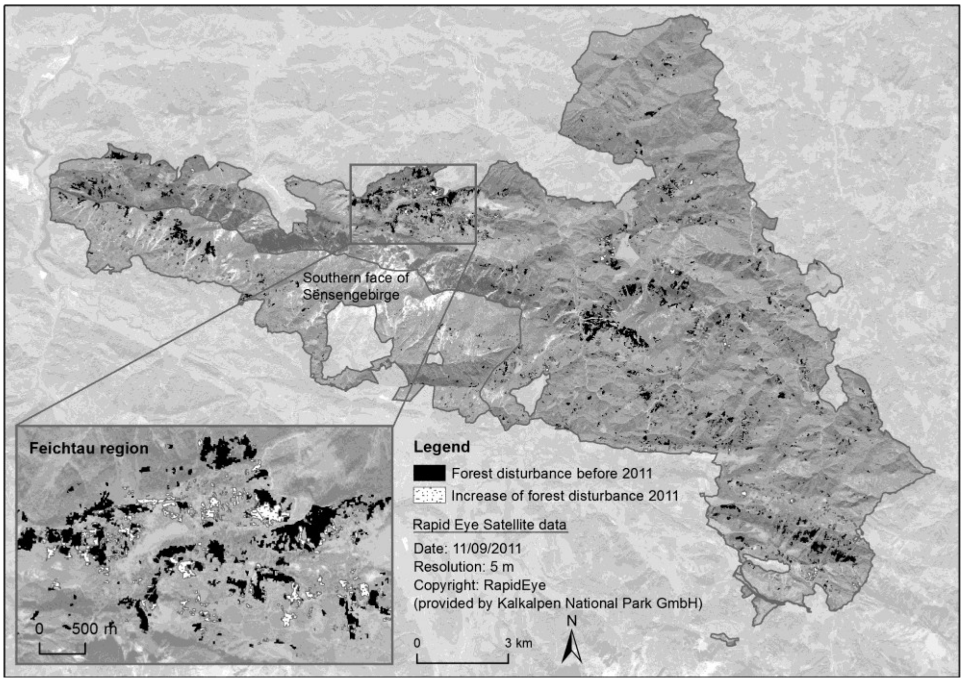

Fig. 3: Forest disturbance up to 2011, overlain by reference data, Feichtau region

In summer 2012 for the Unterlaussa region (south eastern part of the national park) acomprehensivesurvey of deadwood areas before 2011 and their increase in the year 2011 was conducted with one of the four rangers of the national park region. For the validation GPS records and photo documentation of forest disturbances of the year 2009 to 2012 was used. Consequently, it was pointed out that the forest disturbance areas as part of the (semi-)automated object-based analysis were very well captured according to the initial results of the field validation. Sometimes mistakes occurred within rock formations. The detailed accuracy assessment for the forest disturbance indication is still in processes, which also will include expert feedback of the national park administration.

Conclusion

In this research, the authors demonstrated the potential of an object-based forest disturbance monitoring approach in an operational context.In general its strength lies in the repeatability, once the rule sets for the semi-automated analysis system are established. Then it shall offer a robust and economically priced solution for a monitoring system that is likewise useful the local (i.e. site-specific) monitoring and reporting tasks as well as to support the implementation of EU biodiversity policies such as the Habitats Directive.

In terms of an optimization of seasonal aspects we found that a capturing date in September does not cover the net increase of deadwood areas in an unbiased way if the statistics should be valid for the calendar year, since bark beetle attacks are still active. The future system will therefore be based on early summer (May) imagery.

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