TOWARDS ADVANCED FOREST DAMAGE SURVEY: APPLICATIONS OF REMOTE SENSING

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Abstract

Global climatic change can affect forest health by altering the frequency, intensity, duration and spatial scale of insect and pathogen outbreaks, alien invasive species, droughts and storms. Relationship of climatic variables to damage agents makes integrated research and development of advanced methods highly needed. Remote sensing, such as optical and microwave satellite imaging, digital aerial photography and airborne laser scanning, is at its best in various forest monitoring tasks. Development work will be required in several levels in order to produce cost efficient monitoring methods able to forewarn of threatening disorders in time. Integrated European monitoring programmes are needed to determine the sensitivity of different types of pests and diseases to environmental change and their potential for increased outbreaks.

Keywords: climatic change, GIS, laser scanning, monitoring, outbreak, remote sensing

1. Introduction

1.1. Future risks for the European forests

The amount and severity of common forest damage causes such as storms, droughts and pest insects, have recently dramatically increased. Global climatic changes will cause ever increasing financial losses in the forest sector. For example, the exceptional droughts of years 2002 and 2003 damaged alone in the city forests of Helsinki (ca. 4600 ha) more than 17 000 m^3 of growing stock, in financial terms the losses accrued to almost 200 €/ha (Holopainen et al. 2006). The mean value of losses can reach up to 300-500 €/ha/year following insect defoliation (Lyytikäinen-Saarenmaa & Tomppo 2002). Due to a prolonged growing season wood production may increase but the quality of the growing stock and its insect resistance may decrease.

In Central Europe, conifer dominant forests have already had to been regenerated with deciduous tree species because of powerful mass outbreaks of pest insects (Evans et al. 2002). Droughts, in turn, either kill trees directly or expose them to pest insects. Winters in Scandinavia will become mild and rainy and severe frosts will not be experienced. This will ease the overwintering of pest insects and the spreading of fungus diseases (Walther et al. 2002).

In the near future, the frequency, intensity and spatial extent of forest damages will increase. The distributional ranges of various species will shift northwards and pest insects currently causing only occasional damages will transform into major hazards (Ayres & Lombardero

2000, Dale et al. 2000). Changes in land use and forestry will promote the probability of mass outbreaks and invasions. Simultaneous mass occurrences of several species will likewise become more common. Changes in the climate provide potential invasive alien species favorable circumstances which furthers their capability to spread in risk situations (Dukes & Mooney 1999).

1.2. The need for a method development

Methods used so far for managing and monitoring forest damages are highly diverse (e.g. Juutinen & Varama 1986, Kolk 1996, Haffelder & Boehme 2000). Systematic monitoring has usually not been arranged and sampling schemes have not been planned well enough. Work carried out has often been haphazard and highly labor intensive and based on samples taken in the field and laboratory cultivations. Monitoring has not involved compartments or the whole forest ecosystem. Unreliable predictions, haphazardness and short warning times have also proved to be characteristic for the methods used so far.

For the above mentioned reasons there is a need for more efficient methods for monitoring and predicting pest invasions in order to better cope with emerging climatic changes. These methods to be developed will, for their part, ensure the sustainable development of European forests. Application of semiochemicals for monitoring purposes seems to provide promising techniques for stand level estimates (Lyytikäinen-Saarenmaa et al. 1999, 2006), particularly when combined with methods of modern geoinformation.

Rapid development in techniques for acquiring, analyzing and managing geoinformation (GIS) and remote sensing has opened new possibilities in forest inventory and management (Holopainen 1998, Korpela 2004, Holopainen & Kalliovirta 2006). Remote sensing, such as optical and microwave satellite imaging, digital aerial photography and airborne laser scanning, is at its best in various forest monitoring tasks (e.g. Holopainen & Jauhiainen 1999, Yu et al. 2004, Korpela 2004).

2. Application of novel methods for a damage survey

2.1. Aerial photography

Recently numerous studies have been carried out in order to intensify the use of aerial photography. Growing stock characteristics can be interpretated either visually (Anttila 2002) or numerically using field measured data as a reference data (Holopainen 1998). Aerial video, laser and photo imagery have also been used to interpret single tree characteristics (Korpela 2004, Maltamo et al. 2004). Digital aerial photography has also been used for delineating compartment boundaries with specific segmentation algorithms (Pekkarinen & Holopainen 2006). Remote sensing imagery has proven especially important for various monitoring tasks where the availability of inexpensive and regular data is a prerequisite for success. Detailed interpretation of remote sensing imagery can be applied extraordinally well also to the assessment and monitoring of forest health either on the stand or single tree levels (Haara & Nevalainen 2002, Korpela 2004, Talvitie et al. 2006, Holopainen et al. 2006).

False color aerial photography has proven to be more suitable for assessing vegetation health than traditional true color photography (Heller 1978). Signs of vegetation stress can be detected at an early stage before any changes in the reflection of visual wavelengths. The first changes can be observed in the near-infrared wavelength range. Structural changes caused by various factors may either increase or decrease the reflection intensity in the near-infrared spectrum (Esserly et al. 1992). In addition to this range changes can be observed also in other wavelength zones (Franklin 2001). Vegetation reflection increases markedly at the transitional zone between the red and near-infrared wavelengths. In stress circumstances this transition point shifts towards shorter wavelengths. This phenomenon is called the blue shift. Although the direction of the near-infrared reflection change varies depending on the cause of the stress, the direction of the blue shift has been found to be constant (Franklin 2001). Spectral signatures as well as blue shift of stressed vegetation can be detected by means of imaging spectrometer. Basic information on the spectral properties of the objects deduced is acquired which can be utilized in the interpretation of other remote sensing imagery (Holopainen & Kalliovirta 2006).

The use of digital aerial photography and other geographical information for assessing and monitoring forest health has been successfully experimented by the Helsinki University Department of Forest Resource Management in a project launched for assessing drought damages in the forests of Helsinki City and carried out during the years 2003-2005 (Holopainen et al. 2006, Talvitie et al. 2006). Talvitie et al. (2006) developed an inventory method based on adaptive cluster sampling for assessing rare forest phenomena such as drought damages. Holopainen et al. (2006) analyzed drought damage causes with a GIS system using information derived from natural resource plans, precipitation statistics, numerical maps and aerial photography.

2.2. Multiphase sampling for monitoring extensive forest damages

Mapped damage or potential damage areas derived by analyzing detailed remote sensing imagery and field observations constitute the initial data source. These areas can be used as reference, calibration and test data when moving from more accurate to less accurate remote sensing data sources. Forest damage predictions will initially be generalized to larger areas using either small scale digital aerial photography or very high resolution satellite imagery (e.g. IKONOS). The images will first be corrected for radiometric distortions (Holopainen & Wang 1998), after which they will be partitioned into segments (Pekkarinen & Holopainen 2006). The segments will then be used as sampling units for distracting various spectral and spatial image features.

Damage characteristics observed either in the field or measured from detailed aerial photography will then be generalized to the segments by the non-parametric k-nearest neighbour method (Tuominen & Poso 2001). In multi-phase sampling, damage predictions at the most coarse level will be performed using mid-resolution satellite imagery (e.g. Landsat TM, SAR-radar imagery) or low resolution optical or microwave satellite imagery.

2.3. Laser scanning

A laser scanner emits an optical/infrared laser pulse perpendicular to the flight path. Each image row consists of pixels representing nearly adjacent ground elements, based on 3D information on the object (Fig. 1). By analysing these measurements both 3D terrain and crown models can be derived. The difference in these models is the height model of the stock. The physical dimensions of the imaged objects are measured directly. Ground-referenced measurements are therefore not required, which in turn reduces the total costs of forest measurements (Hyyppä & Inkinen 1999).

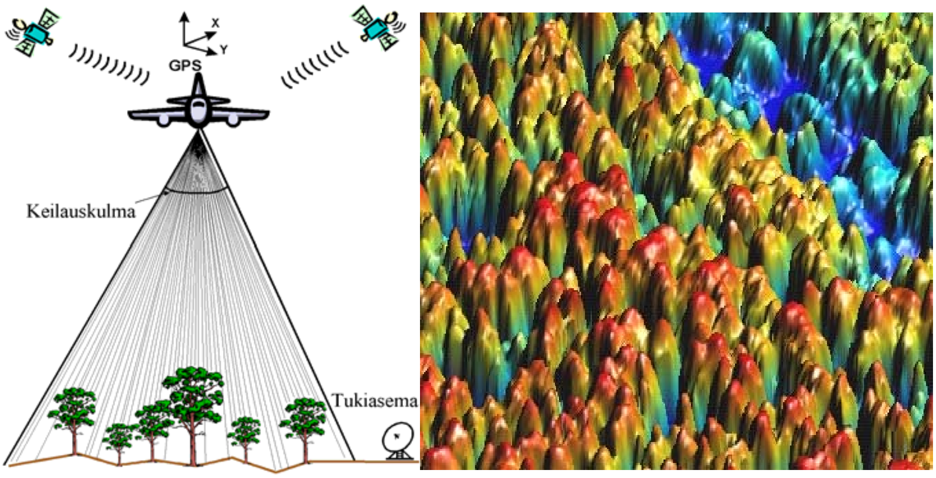

Figure 1. Laser scanning is based on a creation of a 3D tree height model, segmention of individual tree crowns and calculation of plotwise/standwise characteristics based on individual tree parameters. Figure Holopainen & Kalliovirta (2006), image © A. Kukko & J. Hyyppä

Applications of airborne laser scanning in forestry include determination of terrain elevation, standwise mean height and volume estimations, individual tree-based height determination and volume estimation, tree species classification, and measurement of forest growth and detection of harvested trees. The accuracies of laser-scanning estimates at the tree, plot and stand levels are very similar to or better than those achieved in field inventories (Naesset 2004). Tree crowns, trees, groups of trees or stands can be delineated, using image-processing techniques of laser scanner data (Hyyppä et al. 2004). Finding tree locations can be done by detecting local image maxima. After finding the local maxima, the edge of the crown can be found with the processed canopy height model. Tree counts, tree species, crown area, canopy closure, gap analysis and volume and biomass estimation are provided (Gougeon & Leckie 2003).

In coniferous forests 40-50% of the tree could be correctly segmented. Persson et al. (2002) linked 71% of the tree heights with the reference trees. Tree based approach was also used by Popescu et al. (2003). Methods for tree based measurements using laser scanner data are still under development and empirical studies are needed.

3. Discussion and conclusion

There is a small amount of information on the frequency, intensity and spatial extend of disturbances and their impact on forest dynamics. This problem is especially severe for biotic agents and their interaction with abiotic events, e.g. severe drought and heavy winds. Research should identify the impact and change in spatial scale of insect pests and pathogens that are likely to be main agents of future forest damages. Integrated European surveys are needed to determine the sensitivity of different types of pests and diseases to global climatic change and the potential for increased outbreaks of those species, especially at the margins of their distributional ranges.

At the pan-European level, the following steps for integrated measures of forest health management should be followed. First, continuous monitoring on permanent sites under different climatic ranges in Europe is needed. Second, development and application of novel monitoring methods, e.g. false colour and digital aerial photography, and laser scanning should be supported. These methods provide accurate tools for early warning and detecting evolution of outbreaks and damage spots. Third, models and scenarios for outbreaks and distribution extensions at a landscape level are needed. These models should be built for different climatic change scenarios over wide ranges and based on methods of GIS analysis. Fourth, the only possible way to carry out the method development and damage monitoring is to create an intensive European co-operation, e.g. networks, expert systems and large research programmes. And finally, science should be combined to active forest policy, decision making and legislation, on national and international basis. Adaptation to future threats in European forest ecosystems is a joint challenge where all the new ideas should be introduced.

There is an urgent need to develop a management system of forest damages, based on remote sensing and geographical analysis by which the practicing of forestry and sustainability of forests can be adapted to future climatic changes and increasing problems by insect pests and pathogens. Development work will be required in several levels in order to produce cost efficient monitoring methods able to forewarn of threatening disorders in time. Availability of the 2D and 3D data is improving and the costs are decreasing continuously, providing expanding and fascinating applications for forest damage survey.

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