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A GIS-based decision support system for risk assessment of wind damage in forest management

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Abstract

In this study a GIS-based decision support system (DSS) was built for assessing the short- and long-term risk of wind damage in boreal forests. This was done by integrating a forest growth model SIMA and a mechanistic wind damage model HWIND into geographical information system software (ArcGIS 8.2) as a toolbar (DLL) using ArcObjects in ArcGIS and Visual Basic 6. In this DSS complex problems are solved within program so that forest gaps, edge stands and edges are automatically tracked when the forest structure changes over time as a result of forest growth dynamics and management. This DSS can be used to assess the risk of wind damage to Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula* spp.) stands, regarding the number of stands and area at risk and length of vulnerable edges of these risk stands at certain critical wind speed classes (i.e. corresponding the maximum wind speed a tree/stand can resist). This DSS can helps forest managers to analyse and visualise (charts, maps) the possible effects of forest management, such as clear-cuts, on both the immediate and long-term risks of wind damage at both stand and regional level.

Keywords: Decision support system; GIS; Forests; Model integration; Risk assessment; Wind damage

Software availability

Name of software: Geo–SIMA–HWIND. The preliminary software was developed in 2004 and could be available right now.
Developer: Hongcheng Zeng.
Software required: ArcGIS 8.2, 8.3, 9 (with ArcInfo license and ArcInfo Workstation).
Programming language: Visual Basic, ArcObject.
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1. Introduction

The structure and functioning of a forest ecosystem are greatly affected by wind. In addition wind-induced damage is a continuous cause of economic loss in forests. For example, in Europe about 180 million m^3 of timber were blown down during storms in December 1999 (UNECE/FAO, 2000). There was about 70 million m^3 of windthrow in a storm occurred in southern Sweden in January 8, 2005. In Finland, over 7 million m^3 of timber were damaged in a similar manner in November 2001 (Pellikka and Järvenpää, 2003). The economic impact of wind damage is particularly severe in managed forests due to the reduction in the yield of recoverable timber, the increased costs of unscheduled thinning and clear-cutting, and associated problems in forestry planning (Savill, 1983).

The influence of forest management on the risk of wind damage can be found at the tree, stand and regional level (here region is defined as comprising one or multiple management units). In principle, the susceptibility of a forest stand to

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wind damage is controlled by tree and stand characteristics such as tree species, diameter, height and stand density (Coutts, 1986; Gardiner, 1995; Peltola et al., 1999). Since these characteristics change dynamically along with forest growth, the risk of wind damage will also be modified (Slodicak, 1995; Zeng et al., 2006). Wind damage is most likely to be found where there are sudden changes in wind loading to which the trees are not acclimatised, such as in stands adjacent to new clear-cut areas or in stands that have recently been heavily thinned (Neustein, 1965; Lohmander and Helles, 1987; Peltola, 1996a,b; Gardiner et al., 1997; Peltola et al., 1999). However, the risk of damage will decrease over time when trees become acclimatised to changing wind conditions and/or when new clear-cuts are disappearing over time due to growth dynamics of new seedling stands in these gaps (Zeng et al., 2006). On the other hand, large differences in the risk can be observed between regions and locations that differ in topography and wind climate (Talkkari et al., 2000; Zeng et al., 2004).

Various empirical and statistical approaches based on tree and stand characteristics have been applied to assess the risk of wind damage (e.g. Alexander, 1964; Lohmander and Helles, 1987; Valinger and Fridman, 1997; Mitchell et al., 2001; Ni Dhubhain et al., 2001). In addition, mechanistic wind damage models (e.g. HWIND, ForestGALES, FOREOLE), based on the tree and stand characteristics, have also been developed to predict the wind speeds needed for uprooting or breaking the stems of trees (Peltola et al., 1999; Gardiner et al., 2000; Ancelin et al., 2004).

At the same time, statistical and process-based growth and yield models have also been made available to simulate forest growth under certain environmental and management conditions (e.g. Kellomäki et al., 1992; Kellomäki and Väisänen, 1997; Matala et al., 2003). Recently, also commercially available airflow models (Walmsey et al., 1993; Mortensen et al., 2002) have been built for predicting wind speeds, their directions and frequencies at certain locations on a forest landscape as controlled by topography and surface roughness. These different kind of modelling tools could be expected to offer useful tools for the risk assessment of wind damage both at a stand and regional level (Talkkari et al., 2000; Blennow and Sallnäs, 2004; Zeng et al., 2004). In this context, geographical information systems (GIS) could serve as a common data and analyses framework for models (e.g. Rao et al., 2000; Tianhong et al., 2003; Shen et al., 2005).

Different component models can be either loosely linked to GIS software without any common user interface (e.g. Talkkari et al., 2000; Blennow and Sallnäs, 2004; Zeng et al., 2004), or alternatively GIS tools can be applied to different models (e.g. Nute et al., 2004) or the component models can be embedded in the GIS system (e.g. Gardiner et al., 2003; Gyllenhammar and Gumbricht, 2005). A decision support system (DSS), which seamlessly integrates different component models, could be most useful, for example, in risk assessment of wind damage at a stand and/or regional level. In this kind of system: (i) the selected forest stand data and other information can be automatically transferred between GIS database and forest growth and wind damage models. (ii) Complex and invariably time-consuming spatial problems can be automatically resolved within the DSS. Including, e.g., extracting and updating forest gaps, edge stands and edges over time based on spatial relationship between polygons or polylines so that the changes to the forest edges reflecting the forest growth patterns can be automatically tracked. (iii) The dynamics of the stands at risk and vulnerable edges can be automatically identified on maps. Gardiner et al. (2003) have been among the first to embed a mechanistic wind damage model ForestGALES and Yield Class Model into GIS software Arcview as an extension for assessing the risk of wind damage to the forests.

In this study, a DSS was built for the risk assessment of wind damage in Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula* spp.) stands at both a stand and regional level in Finnish conditions. It was completed by embedding the mechanistic wind damage model HWIND (Peltola et al., 1999) and the forest growth model SIMA (Kellomäki et al., 1992) into GIS software ArcGIS as a toolbar. The aim is that both the immediate and longer term (over decades) risks of wind damage as a consequence of any changes in forest structure due to forest growth dynamics and management (e.g. clear-cuttings) could be evaluated and visualised (charts, maps) in DSS, i.e. regarding the number and area of stands and length of vulnerable edges at certain critical wind speeds (maximum wind speeds that stands can endure).

2. Development of the decision support system

2.1. Framework of the system

In this study a GIS-based decision support system (DSS) was built for assessing the risk of wind damage by integrating a forest growth and yield model SIMA and a mechanistic wind damage model HWIND into GIS software ArcGIS 8.2 (Fig. 1). ArcObjects in ArcGIS and Microsoft Visual Basic 6 were used

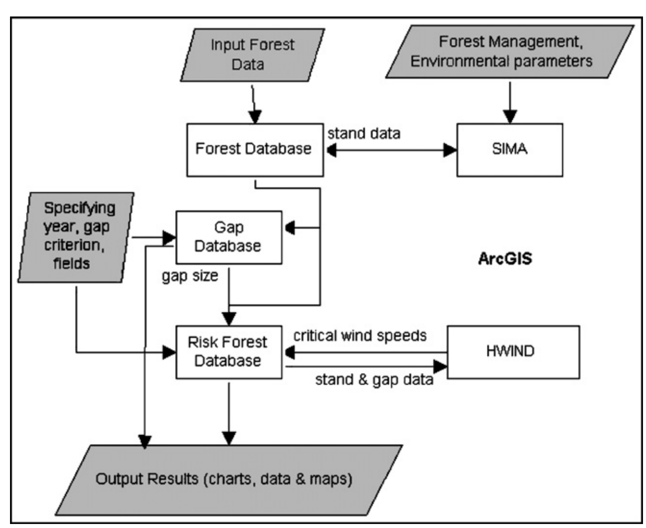

Fig. 1. Framework of the system (Note: oblique grey rectangles have user interfaces.).