Environmental Modelling & Software 69 (2015) 63–76

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Coupling a tree growth model with storm damage modeling – Conceptual approach and results of scenario simulations

Axel Tim Albrecht [a,*], Mathieu Fortin [b], Ulrich Kohnle [a], François Ningre [c]

[a] Forest Research Institute Baden-Wuerttemberg, Wonnhaldestr. 9, 79100 Freiburg, Germany
[b] AgroParisTech, 14 rue Girardet, 54042 Nancy, France
[c] Institut National de Recherche Agronomique (INRA), Centre de Nancy-Lorraine, 54280 Champenoux, France

ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form
5 March 2015
Accepted 6 March 2015
Available online

Keywords:
Windthrow
Storm damage
Forest growth
Statistical modeling
Forest management
Scenario simulation
Risk avoidance
Risk reduction
Disturbance modeling

ABSTRACT

The purpose of this study was to develop, test and evaluate a software prototype capable of modeling forest growth in consideration of winter storm disturbance and to simulate storm damage in forests under different forest management regimes. The results of a test application showed that simulated storm damage was more strongly influenced by the input data (e.g. tree species and tree height) than by the different forest management regimes. However, early, intense thinnings as well as reducing target diameters by 10% led to reduced storm damage, with decreases as large as 50% of the damage in certain forest stands. The coupled modeling framework was able to simulate interactions between forest growth, storm damage and forest management regimes. Further testing of the prototype appears necessary to investigate a wider range of tree species, soil and site conditions. Also, the use of computational system resources needs improvement.

Software and/or data availability

Software is available from the authors upon request. Also the data of the model forest stands are available as tree lists for BWinPro from the authors upon request.

1. Introduction

Forest growth is often predicted without considering natural disturbances such as storms, wildfires, or bark beetle infestations. In fact, the inclusion of these disturbances into growth simulations is hindered by the uncertainty associated with the frequency of these phenomena (Schelhaas et al., 2003). Furthermore, the driving factors of forest growth, such as soil fertility, precipitation and competition, differ from the factors causing storm or insect damage (Hanewinkel et al., 2011). Furthermore, predicting the occurrence of storms or favorable habitat conditions for bark beetles requires consideration of spatial scales different from those needed for modeling growth of an individual forest stand. Thus, current software requirements differ between growth models and risk models, leading to independent software architecture and design for these two environmental phenomena. While both risk and growth modeling are still facing challenges each within their disciplines, the difficulty of coupling them has just recently been tackled (Seidl et al., 2014).

Another reason why forest growth and natural risks have not yet been interactively linked in a modeling framework may be that forest scientists and managers have – until now – frequently perceived damage from catastrophic disturbances as non influenceable. For this reason, forest growth has usually been modeled without any consideration of large-scale disturbances, while the effects of these disturbances have been summarily evaluated *ex post*, for example, in terms of standing wood volume potentially at risk, potential reduction of harvest revenue under risk, or with survival functions (Dieter et al., 2001; Knoke et al., 2008; Neuner et al., 2014; Staupendahl and Möhring, 2011).

* Corresponding author. Forest Research Institute Baden-Wuerttemberg, Wonnhaldestr. 4, 79100 Freiburg, Germany. Tel.: +49 (0)761 4018277; fax: +49 (0)761 4018333.
E-mail addresses: axel.albrecht@forst.bwl.de (A.T. Albrecht), mathieu.fortin@agroparistech.fr (M. Fortin), ningre@nancy.inra.fr (F. Ningre).

http://dx.doi.org/10.1016/j.envsoft.2015.03.004
1364-8152/

Previous analyses of biotic and abiotic risk in forestry have often led to recommend a reduction of standing wood volume or target diameters (Beinhofer, 2007, 2010; Roessiger et al., 2011). Thus, there are indications that the risk of storm damage in forests is sensitive to forest management actions and influenceable (Achim et al., 2005; Dobbertin, 2002; Jalkanen and Mattila, 2000; Lohmander and Helles, 1987; Mason, 2002; Mason and Quine, 1995; Quine et al., 1995; Slodicák, 1995). However, many of the recommendations for risk minimization have been elaborated without considering the interaction between forest growth, disturbances and forest management. Forest growth modeling offers the opportunity to implement risk aspects and to serve as an essential tool to better understand and predict these vital interactions.

Forest growth modeling generalizes growth processes of woody plants and quantifies growth on different temporal and spatial scales, usually as some form of biomass increment. A major objective of forest growth modeling is to predict the availability of wood resources for human usage and it helps to understand the underlying drivers of growth (Munro, 1974; Porté and Bartelink, 2002; Vanclay, 1994). Beside other areas of application, different forest management scenarios can be compared based on forest growth simulations (Pretzsch et al., 2002). Such simulations allow, for example, the evaluation of mitigation strategies in changing environmental conditions.

Storm damage modeling in forest sciences specifically analyzes the causes of and the circumstances associated with tree failure in strong winds. A major objective here is to minimize storm damage in forests by understanding the risk factors and the relationships between them, e.g. how the risk of damage can be altered by human action (Gardiner et al., 2008; Gardiner and Quine, 2000). Storm damage modeling serves as a basis for developing risk management strategies (Hanewinkel et al., 2011) and insurance models (Holecy and Hanewinkel, 2006). Other objectives of storm damage modeling are, for example, visualization of landscape dynamics or analyzing the vegetational succession dynamics (Ulanova, 2000).

Landscape-scale interactions on the relation between storm damage and forest management have been illustrated for managed forests only in a few studies. In Finland, Zeng et al. (2007) have focused on the response of newly exposed forest edges after clearcutting to the risk of subsequent storm damage. In the United Kingdom, Gardiner et al. (2003) have designed a framework to calculate windthrow risk for empirical forest stand data. Based on these two approaches damage risk for entire regions was estimated, including some dynamic aspects of growth and the impact of forest management on storm risk. Another regional study analyzed the relationship between ecosystem services as a function of several factors, such as forest management alternatives, climate change impact and disturbances caused by storms (Ray et al., 2014). Another recent study in this context combined a process-based model of wind-disturbance with a forest growth model (Seidl et al., 2014). Although not explicitly performed in this study, this approach allows to analyze the impact of alternative silvicultural treatment regimes on storm damage by scenario simulations.

Quantifying the effect of disturbances on forest growth and the impact of forest management on the risk of damage is difficult and is associated with high natural variability. While some previous studies have demonstrated the usefulness of combining forest growth models with storm risk models and GIS (e.g. Gardiner et al., 2003), some questions remain unanswered, especially regarding the effect of different thinning regimes and partial harvesting on remaining stands. Therefore, the objective of this study was to propose a modeling framework that combines natural risks, forest growth and forest management. To achieve this, we coupled a storm damage model and a forest growth model. Different management scenarios were then tested to quantify the simulated damage. Our working hypotheses were that

(H1) storm damage has significant impact on forest growth
(H2) the amount of storm damage is sensitive to forest management regimes

We used the German federal state Baden-Wuerttemberg in southwest Germany as a case study and focused on the two tree species Norway spruce (*Picea abies* (L.) H. Karst.) and Silver fir (*Abies alba* Mill.).

2. Material and methods

2.1. Growth model

We used the distance-independent individual-tree forest growth simulator BWinPro developed by the Northwest German Forest Research Institute (Hansen and Nagel, 2014; Nagel et al., 2002). The simulator is based on five-year growth intervals. Simulations for longer time intervals are obtained by reinserting the predictions in the model as many times as necessary to reach the desired projection length. For each five-year interval, the simulator performs the following sequence of steps:

1. if required, a user-specified treatment is carried out and the competition indices of remaining trees are updated;
2. competition- and age-induced mortalities are simulated;
3. competition indices of survivor trees are updated;
4. diameter and height increment of survivors is simulated;
5. competition indices are updated (post growth but before next treatment). Loop back to step 1.

The simulator uses a forest stand consisting of individual trees in a tree list as its simulation unit. Competition between individuals in a stand is modeled through a distance-independent competition index. The competition for a particular tree is expressed as the competition induced by all other trees in that stand, regardless of their distance.

Forest management in BWinPro can be defined in the sub-modules for thinning, harvesting, and planting operations.

The following options are available in the thinning module:

- type of thinning (e.g. thinning from below, thinning from above or thinning with permanent target crop trees)
- minimum stand height for first thinning
- the intensity of thinning, ranging from none to heavy
- minimum and maximum standing wood volume to be removed by thinning operation.

Harvesting operations can be defined by the following parameters:

- type of harvest (individual target diameter, shelterwood harvest, clear cut)
- speed of progress for shelterwood harvest

BWinPro is adapted for stands with homogeneous structure, which means the tree diameters follow a unimodal distribution, and can be used for single- or mixed-species stands. As a decision support tool it is especially suitable for the comparison of different forest management options. This growth simulator is based on empirical forest growth data measured in long-term monitoring plots and it was originally developed for the growth conditions in northwest Germany (Nagel et al., 2002). As the geographic context in southwest Germany varies from the original parameterization data (northwest Germany), we re-parameterized the simulator's four basic growth equations using data from southwest Germany (Albrecht et al., 2011, 2012b). The simulator was implemented in software using the Java language (website in German: http://www.nw-fva.de/?id=194).

2.2. Storm damage model

The storm damage model (SDM) was developed for six major European tree species groups and represents storm damage from three large-scale winter cyclones (1967, 1990, 1999) as well as dispersed damage from minor storms that occurred between 1950 and 2007 in long-term experimental plots located in southwest Germany (Albrecht et al., 2012a). Since it is based on observed storm damage it is considered an empirical SDM, in contrast to mechanistic SDMs which are primarily based on the predicted mechanical behavior of trees under wind loading (Gardiner et al., 2008).