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A demonstrator of models for assessing wind, snow and fire damage to forests using the WWW

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Abstract

A demonstration package of predictive models for assessing the risk of forest damage from wind, fire and snow has been produced which can be accessed via the World Wide Web (WWW). The paper describes how this demonstration provides a common point of access to the models and to the research that underpinned their development. The matching of model requirements to available data is described, examples of the inputs and outputs of different models that operate at national level and site level are presented, and the benefits of such a demonstrator and use of the WWW in research are also discussed.

Keywords: Model demonstration; Metadata; World Wide Web

1. Introduction

Forest damage by wind, snow and fire is the most serious economic problem facing the forest industry within Europe. Hundreds and millions of ECUs are lost to abiotic damage each year (Doll, 1991a, b; Nykanen et al., 1997) and further losses in timber and forest quality result because the abiotic damage makes a stand more prone to consequential damage (Valinger et al., 1993; Valinger and Lundqvist, 1994).

A large body of forest research has been concerned with investigating the different aspects of abiotic causes of tree damage and several models have been developed in Europe which describe the risk of damage to forests (e.g. Petty and Worrell, 1981; Laiho, 1987; Hirvela and Hynynen, 1990; Valinger et al., 1993; Vasconcelos et al., 1993; Gardiner, 1994; Neves et al., 1994). These models work in different ways, are based on diverse algorithms, using data at a range of scales, and are of different types and, although they have a number of factors in common, such as a need for data on wind, or data on tree species or vegetation cover, the majority of models related to abiotic damage operate, or are used, independently of one another.

A number of variables are shared by many models, such as parameters on soil type, tree height, spacing and climatic factors, although the definition of an apparently common variable may actually be different (Kellomäki and Peltola, 1998). The outputs from these models include the wind speeds required to cause

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overturning or stem breakage, and the risk of damage (e.g. Peltola and Kellomäki, 1993), whereas the fire model produces predictions of the spatial distribution of the risk of fire and its spread (e.g. Vasconcelos and Guertin, 1992). A single point of access to such models provides researchers, and those with a commercial interest, an information resource about modelling potential damage due to wind, snow and fire.

A demonstration framework has been developed from which users can access data on damage models, working examples of model input and output, and supporting research into some of the factors which cause, or influence, abiotic damage. This paper describes the approach adopted to present and demonstrate the outputs of the models, and illustrates their potential use in evaluating and explaining management strategies for minimising damage to forests.

2. Demonstration framework methods

2.1. Design considerations

A framework was developed to support access for the demonstration of component models, or model results, and research materials. The design was planned such that the user, irrespective of their requirements and purpose, should have access to sufficient supporting research to make an informed assessment of the causes and consequences of each type of abiotic damage. Information was to be made available at increasing levels of sophistication, with examples of interactive models at a regional and stand level, and how such models may be used to illustrate their use for assessing the risk of damage based on the use of alternative management scenarios. Guidance on the reliability and uncertainty of the outputs associated with model inputs, together with summaries of the information on risk management available within the published literature, and new research on issues that underlie the development and validation of the damage models, would provide a user with a broader context with which to assess the value of the predictions. Finally, a contact route to the model developer could enable access to operational versions of the models.

Four approaches to the structure of the demonstration framework were considered for combining the models into a single point of access. These are: (1) a WWW-based hypertext system; (2) a Geographic Information System (GIS), with embedded macros; (3) a single package with bespoke software and with routines for each model; (4) stand-alone packages for each model.

Each of the GIS, single package and stand-alone options has been used before for similar exercises and thus the benefits and potential usefulness, and the associated limitations, have been previously proven (Leavesley et al., 1996; Vckovski and Bucher, 1997). For the current framework, however, a WWW based structure was chosen, since this offered the greatest flexibility for independent model development and testing, and facilitated the updating and refinement of individual models. It also enabled the incorporation of a disparate array of contents for the presentation and operation of models, the supporting research and the dissemination of the research content and results, in a way that could be updated centrally, yet permit worldwide access, using widely available, standard and low cost computing facilities.

The interface provides a ‘Subject Menu’ to enable the user to change between different type of demonstration, and a ‘Content Menu’ to provide access to the geographical region, damage agent or explanations of the demonstration selected.

2.2. Component models

Eighteen models were included within the demonstrator, based around the four approaches summarized below:

1. HWIND (Peltola et al., 1999) — a mechanistic model that was developed in Finland for assessing the wind speeds at the canopy top required to cause stem breakage or tree overturning, using tree and stand characteristics (e.g. DBH and height) as inputs. A GIS has been used to couple the model with information held within a forest inventory.
2. ForestGALES (Quine, 1998) — an empirical–mechanistic model that was developed in the UK for predicting the probability of stem-breakage or overturning from site and tree characteristics, at the level of a forest stand. The model uses a GIS in the pre-processing of some data (e.g. derivation

of windiness), and in the presentation of the results.

3. 'Valinger' models — a set of 14 logistic models for predicting stem-breakage of single trees, based on a selection from the six 756 permanent plots recorded within the Swedish National Forest Inventory (Valinger and Fridman, 1997; Fridman and Valinger, 1998).
4. FIREMAP — a rule-based model that was developed in Portugal, for calculating the potential rate of spread of fires. This model uses fuel maps derived from satellite imagery and other stand level data, such as wind speed, temperature and humidity as inputs, represented within a GIS, and includes in its outputs estimates of fire danger levels and maps of flame length and fireline intensity (Uva et al., 1997).

Table 1 summarizes the nature of the models which form the inputs to the framework and the nature of the coupling to a supporting GIS for pre- or post-processing of the results. Although the GIS facilities are an important element in the operational use of the models, as indicated in Table 1 under 'Framework implementation', the demonstrations are limited to running on the development and validation data for Finland, the United Kingdom and Portugal. The framework does not include a GIS capability, but instead provides for access to GIS packages when used on a PC with the appropriate software hosted locally.

2.3. Model requirements

A standard approach has been taken to describe the models, based upon the approach developed by the NSDI (1996), and Rhind (1997), which involved the collection of metadata and metamodel information. The metadata format was designed to capture the key aspects of the data, including details of its lineage, accuracy, content and ownership, in addition to information about its structure and format (Lanter, 1993). The metamodel information consisted of details of model derivation (such as source scales and data); validity and sensitivity testing (providing a qualitative or quantitative assessment of the sensitivity of the models to each input); version and release details and points of contact for the modeller.

This documentation allowed the identification of the inputs common to each model and provides a basis for matching the model (and thus the modeller) to the data available to the user. It also allowed the consideration of model limitations, an assessment of error propagation through models, and the investigation of issues associated with spatial integration (such as spatial variability, spatial resolution and adjacency effects).

While this information is essential for competent model usage, making the data available via the WWW would enable users to have direct access to numerical values such as those in equation variables and constants and this may be undesirable with respect to models of a commercial nature. A 'Model Require-

Table 1
Summary of component models and their implementation[a]

Level	Model	Damage agent	Type	GIS coupling	Framework implementation
Tree	HWIND	Wind and snow	Mechanistic	–	Illustrative, on-line
	ForestsGALES	Wind and snow	Empirical	–	Illustrative, on-line
Forest	HWIND	Wind and snow	Mechanistic	Loose coupling (Arc/Info)	Interactive, illustrative, on-line
Stand	ForestGALES	Wind and snow	Empirical–mechanistic	Close coupling (Idrisi)	Interactive, illustrative, on-line
	Valinger	Wind/snow	Logistic	–	Interactive, on-line
Regional	FireMap	Fire	Rule-based	Close coupling (Idrisi)	Interactive, on-line
National	Valinger	Wind/snow	Logistic	–	Interactive, on-line

[a] Notes: (1) HWIND and ForestGALES operate with an optional snow loading, but the Valinger model combines the damage agents into the risk models. (2) There are 14 Valinger models which operate on different species and in different regions. The operation of HWIND and ForestGALES at a forest stand level is via a spatial allocation of the input variables.

Data for largest tree in plot or individual tree

- [x] Volume over bark
- [x] Breast height taper
- [x] dbh
- [ ] low taper
- [x] Clear bole length
- [x] Ratio of height to dbh
- [x] Crown length
- [x] Distance from edge
- [x] Relative crown length
- [x] Height
- [x] Upper taper

	Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	You have
Tree characteristics	species															15	16		●
	Volume over bark	1	2	3		5					10								●
	Clear bole length	1				5		7		9					14				●
	Relative crown length	1		3	4	5		7			10								●
	Breast height taper	1	2				6												●
	Ratio of height to dbh	1		3	4	5	6	7			10				14		16		●
	Height		2			5							12			15	16		●
	dbh		2			5		7						13		15	16		●
	Crown length		2										12						●
	Upper taper				4							11	12						●
	low taper						6												
	Models available	●	●	●	●	●		●									●		

Fig. 1. Snapshot taken from part of the model selection pages. The user selects those data that are available by placing a tick in the check box (e.g. 'Volume over bark', but not 'low taper') and clicks on a find models button (not shown). The selected options are compared to the model requirements and a WWW page is generated that indicates the available data with red dots at the right hand side of the table, and the available models along the bottom of the table. In this example seven models are available. The user can then find out further details of the model and contact details by looking up the model number in a key. Note that this example only indicates data relating to the largest tree within a plot, the demonstrator also includes data relating to the stand, site and climate which have not been indicated here.

ments' option was created within the demonstration to allow a user to specify up to 37 different datasets, grouped together under different types of data (e.g. DEMs or fuel map), tree characteristics, site characteristics, stand characteristics and climate. An example of the structure and outputs from the model requirements interface is illustrated in Fig. 1. The user identifies which data are available and the software calculates those models for which the data is sufficient. The results are reported and the user can select from the models that have been identified as being available for use. The results also provide electronic mail contact to the model developer to facilitate discussion of specific requirements. However, at this stage of the demonstration, little guidance is given on the suitability of any particular model with respect to the source scales or coverage of the data. Further guidance is provided at the stage of model demonstration.

3. Demonstration framework results

3.1. Interactive models

The demonstrator allows the user to interactively calculate probabilities of damage for stands in various European countries. To initiate the interactive demonstration of the models relating to wind and snow damage, the user is presented with a choice of four tree species: Scots pine (*Pinus sylvestris* L.); Norway spruce (*Picea abies* (L.) Karst); Sitka spruce (*Picea sitchensis* (Bong.) Carr) and birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) and country, or region, of interest (Finland, United Kingdom and North-, Mid- or South Sweden). Only those combinations of country and tree species for which the models have been tested are made available.

Currently, the logistic models of wind and snow damage, as presented for Sweden at a national level, are operating in real time on the data options and location selected interactively by the user. The interface uses the standard format of: (1) a map of the country on the left of the content area; (2) a button bar for selection of instructions for use of the demonstration; notes on the model and its data, and email access to the developer; (3) options for the selection of inputs to the model variables such as soil type, tree species, tree height, crown length, altitude and location.

In each demonstration, the user is provided with an example of the effect that uncertainty in model inputs will have on the calculated results. While uncertainty exists in many parameters, only uncertainty in height is demonstrated, since this was an input parameter common to all of the wind and snow damage models. The output of the estimated risk of damage is presented to the user, together with an estimate of the risk with a 20% error in the tree height data. An example of the demonstration interface for Finland is shown in Fig. 2, for the edge of a stand of Scot pine, with no snow loading, on a podzol. The model has calculated that a wind speed of 24.9 ms^{-1} would cause stem breakage, whereas a wind speed of 23.6 ms^{-1} would result in overturning.

3.2. Illustrative models

The input options and results of model runs are presented for study forests in Finland, the United Kingdom and Portugal. These examples illustrate how each model can be used either to show the effects of different silvicultural strategies on the spatial distribution of the risk of damage, or to compare between different models using the same input data. In each case, the user can view the inputs to the models (e.g.

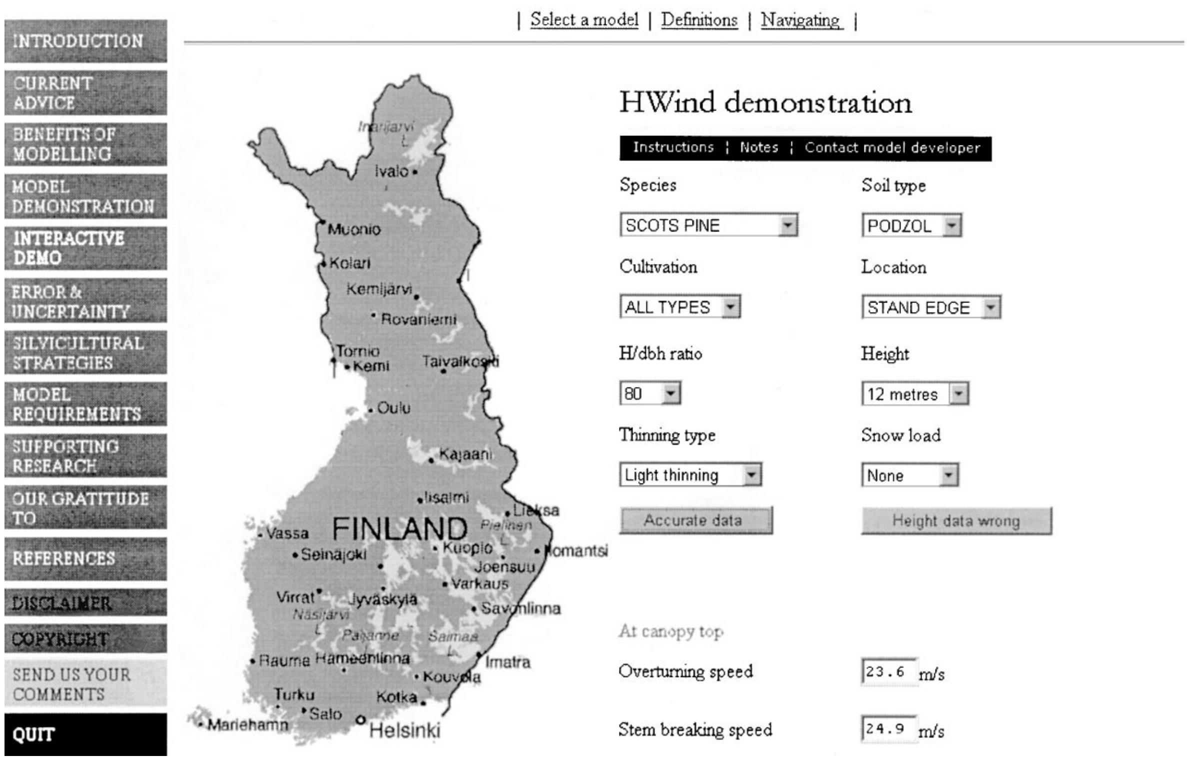

Fig. 2. Example output for the model for Finland. The user enters values for species, soil type, location of the tree within the stand, height, height/diameter ratio, thinning and snowload. The example indicates the wind speed required to cause damage by either overturning or stem breakage for Scots pine stands, but Norway spruce and birch stands can also be assessed. The effect of a 20% error in height data can also be investigated.

maps or satellite imagery) for operation at a forest or stand level, and the associated pre-calculated outputs. For example, the contents of the Finnish forest includes a detailed description of the working of the component aspatial models (HWIND and a Valinger risk model) and spatial modelling (HWIND and a Valinger model, coupled to a GIS) as applied at the level of a forest stand.

The examples of fire risk in Portugal demonstrate the sensitivity of an area to fire spread, with respect to different wind directions and speeds, temperatures and humidity. The user can select from these variables and obtain a map of the risk of fire (in four classes) and a statistical breakdown of the proportions of the study area ascribed to each risk class. The consequences of selecting different fire reduction strategies, such as the addition of fire breaks or removing areas of high fuel loading, is summarized, illustrated and described in terms of potential effectiveness.

Finally, the demonstration of a study forest presented for the United Kingdom uses data for the Cwm Berwyn forest in mid-Wales (Jackson et al., 1999) and includes scenarios of the impact of different management decisions on the wind speeds required to cause tree-overturning or stem-breakage, and the levels of risk of either form of damage. An example output is presented in Fig. 3, which shows the differences between the risk of tree-overturning in 1997, and the potential levels of risk due to the thinning or non-thinning of the forest. The outputs are shown for the risk levels in 2015 (when the trees will be at their maximum mean annual increment), together with the risk estimates when errors in tree height of 20% are included.

3.3. Supporting research

In addition to the modelling tools, supporting research is presented which provides descriptions of research methods and results on several aspects of related work that has been undertaken in the development of the models, their validation or for improved understanding of associated issues. This research includes experiments and results on crown and wood properties of individual trees, changes in whole stem/root system stiffness over time, the use of photogrammetry for the measurement of tree height, the development of a spatial snow model

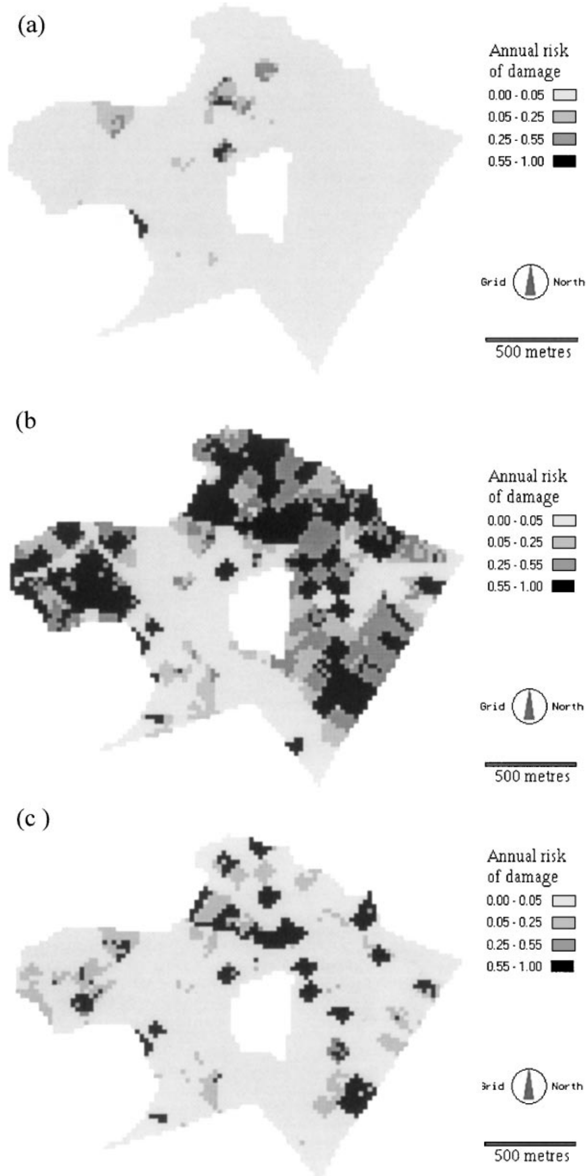

Fig. 3. Example of the potential consequences of different management decisions on the levels of risk of tree-overturning, for Cwm Berwyn forest in mid-Wales (SN 740565) showing the calculated risk of overturning in 1997, and the year 2015 if either a thinning or a non-thinning regime is followed until that date. (a) Risk of overturning: 1997; (b) Risk of overturning with thinning: 2015; (c) Risk of overturning with no thinning: 2015.

for the United Kingdom, examples of the errors and uncertainty associated with modelling using GIS modelling.

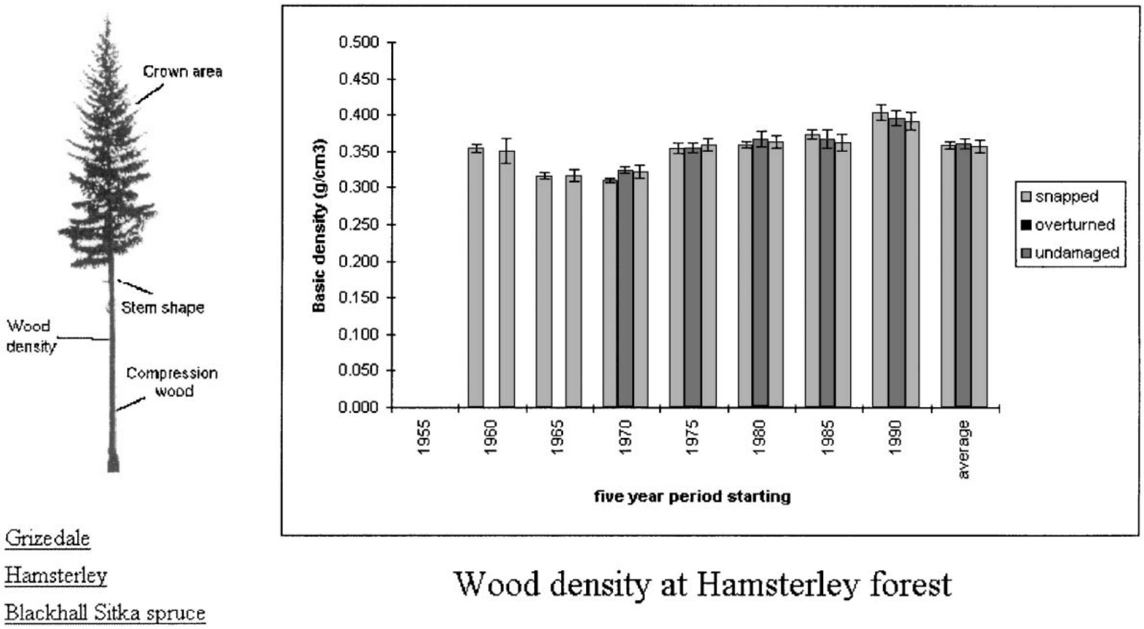

Fig. 4. Example of information about basic research conducted within the STORMS project. The user selects a site (in this case Hamsterley forest in northern England) and a tree characteristics (in this case wood density), and a graph of the data is displayed, along with textual information (not shown).

A specific example of this integration of the supporting research into the framework is in the experiments on wood quality and damage by wind and snow (Dunham and Cameron, 1999). The user is offered a diagram of a tree with crown area, stem shape, wood density and compression wood as variables that were compared at three study sites in the United Kingdom. Diagrammatic and statistical information is presented, together with descriptive and discursive text on the relationships between trees that have snapped, overturned or remain undamaged. The WWW implementation (MLURI, 1998) facilitates access to each component of the research and an example of this aspect of the demonstrator is shown in Fig. 4. The figure illustrates the wood density of trees for the seven, five year periods prior to the stand being damaged by a wind storm which resulted in an intimate mixture of overturned, snapped and undamaged trees.

4. Discussion and conclusions

The models presented in this paper are undergoing further development, and the content and nature of the demonstrator is therefore subject to review. The use of a WWW based demonstration framework, however offers several advantages, including a modular structure that is simple to extend or modify as further information becomes available. Furthermore, it also offers a common means of presentation and ease of access by local or international users, employing standard, low cost, computing equipment.

However, the approach chosen also has certain disadvantages. Currently, the WWW is still underdeveloped for coupling models and GIS functionality ‘on the fly’, and while this problem is being resolved rapidly as technology advances, other issues must be addressed. Firstly, allowing ‘live’ access to the modelling tools implies that either the models are held centrally, in which case data must be transferred across the internet, or else the models themselves will be transferred allowing users to access them on their local machine. While dissemination of models would allow their use in situations with a slow or no connection to the internet, it also has two major disadvantages. It exposes the models to copying, modification and reverse engineering which has implications for models which have a financial value, since this value may be reduced or lost. Also, if models are disseminated, then users may fail to 'upgrade' to subsequent versions of the model, so that outputs may be unreliable. In contrast, if models are held centrally, and the data is transferred across the internet, then updated models can be 'plugged in' to the demonstrator as they are developed, ensuring that only the most up to date versions are being used.

Secondly, the reliability of both models and data is the most critical issue associated with the use of a demonstrator. Several possible sources of error have been discussed, and indications of the magnitude of uncertainty in model outputs have been presented. If the range of modelling tools available were to be developed for operational use, a more comprehensive assessment of the propagation of error would be required, and enhanced access to metadata and meta-model documentation, where it did not compromise the intellectual copyright of commercially valuable models.

The WWW-based demonstration facility described in this paper is currently being used by organizations involved in the education and training of foresters and natural resource scientists, and also for tutorial materials in courses dealing with GIS and spatial modelling. There are, however, two principal limitations to the demonstrator. Firstly, from a user's perspective, the focus of the work is on conditions and causes of abiotic damage that occur in Europe. Although the underlying scientific principals apply widely, the specific conditions under which the models have been developed and tested may not be as widely applicable, so that the models may not be transferable to other parts of the world without modification, and such modification may be extensive.

Secondly, only the logistical models for Sweden are available in their entirety via the demonstrator. The use of the other models, with the user's own site level data, is not currently possible due to issues of intellectual and commercial confidentiality and, current, technical constraints with regard to their efficient implementation on the WWW. However, the collection of methods, research and examples into one location provides a new source of information for devising silvicultural systems to reduce losses of woodland due to wind, snow and fire.

A further area requiring attention would be that of liability for the consequences of decisions made based upon predictions derived from the demonstrator models. An extension of the purpose and objectives of a demonstrator for use with user supplied data, particularly if available via the internet, could require more extensive disclaimers to be presented to a user. However, this level of decision support is not an objective of the demonstration package and thus this issue has not been addressed in depth.

In summary, the paper has presented a description and discussion of the issues associated with an approach to presenting different types of models into a single point of access. Further development of this type of work could significantly benefit potential model users by offering a choice of tools for quantifying the risk of damage to forests and guidance with respect to model applicability.

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