What Science Can Tell Us

Living with Storm Damage to Forests

Barry Gardiner, Andreas Schuck, Mart-Jan Schelhaas,
Christophe Orazio, Kristina Blennow and Bruce Nicoll (editors)

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To the memory of Marie-Pierre Reviron

Contents

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Foreword

Windstorms are a major disturbance factor for European forests. In the past six decades wind storms have damaged standing forest volume, which on a yearly average equals about the size of Poland's annual fellings. The evidence also indicates that the actual severity of storms in the wake of climatic changes may increase during the next decades.

Windstorm damages have many environmental, economic and social implications. Consequently, it is important to try to prevent these damages, and better manage those which cannot be prevented. For this purpose, we need to better understand the many-sided impacts of windstorm to European forests and forestry, and the possible actions which help to minimize the occurrences of damage and how to manage them. It is exactly these issues that this report is addressing and providing valuable synthesis and insights.

In the above context, I want to pick up one direct and valuable contribution of this publication. The European Forest Institute (EFI) is in the process of investigating the role of a *European Forest Risk Facility Network*, which would address the major potential disturbances for European forests, and provide support through scientific information and analyses that will help to prevent, control and manage these disturbances. It will ensure we build on the extensive knowledge and expertise existing within Europe and beyond. To this initiative, the current study provides a helpful background by addressing one important risk factor. It also sets an example of a quality study, which could work as a role model for similar studies to be produced by such a Facility in the future.

The publication is written by a group of renowned natural and social scientists. I would like to congratulate the editors and authors for their excellent work, and for translating scientific information into a format which can be used not only by scientists, but even more so by professionals, stakeholders, policymakers, students and anyone interested in the topic.

I would like to especially thank Gert-Jan Nabuurs and Jean-Claude Ruel for reviewing the manuscript and providing valuable comments and suggestions.

This assessment would not have been possible without financial support from the Ministry of Rural Development and Consumer Protection, Baden Württemberg (MLR), the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), and the National Institute for Agricultural Research (INRA), France.

Finally, I would like to join the editors in their dedication of this book to Marie-Pierre Reviron. She worked at the Atlantic European Regional Office of the European Forest Institute – EFIATLANTIC during 2009 and 2010. She played a leading role in the EFIATLANTIC co-ordinated project for the European Commission on "Destructive storms in European forests: past and forthcoming impacts", which was the catalyst for this book. Her colleagues at EFIATLANTIC and at other EFI locations as well as the project participants remember Marie-Pierre for her enthusiasm in her work and for her warm heart alike. Her unexpected death in August 2010 touched our research community deeply.

I wish you interesting and valuable reading.

Lauri Hetemäki
Editor-in-chief, *What Science Can Tell Us*-series

Introduction

Barry Gardiner

Wind is a major disturbance agent in forests and a key part of the dynamics of many forest ecosystems, particularly temperate forests. Therefore, to understand how forest ecosystem function, and to gain insight into the structure of forests and the evolutionary processes at work, we need to understand the mechanisms and occurrence of wind damage. In addition, the high levels of damage that can occur in storms have important economic, environmental and social consequences, particularly for managed forests. For example, in Europe more than half of all the damage to forests by volume is due to wind and there is a worrying increasing trend in damage levels. Understanding the process of wind interactions with forests, the impact of forest damage, the potential for preventive responses, and the prospects for the future are therefore important for people engaged in the forest based economy, for forest ecologists, for regional planners, and for anyone concerned with the continued sustainability of forests and the forestry sector.

This book has been prepared by 27 experts and attempts to bring together in one place the latest scientific understanding of the many facets of storm damage to forests. It extends a comprehensive review of the impact of destructive storms to European forests commissioned by the European Commission Directorate General for the Environment published in 2011. The book is designed to give a thorough and wide-ranging review of each aspect of storm damage in a format and style that is readily accessible to specialists and non-specialists alike and provides recommendations for further reading for those who wish to explore topics in more details.

The book starts with an introductory chapter (Chapter 1) that sets the scene by reviewing the history of storm damage to forests, the trend in damage with time, and compares the levels of damage due to storms against other damaging agents such as insects and fire. It provides a basic background to the climatology of storms, the types of storm damage that can occur and when these damaging events are most likely to occur. Finally it helps the reader understand the scale of the issue by illustrating the impact of a number of the very severe storms that have affected Europe between 1999 and 2009.

Chapter 2 provides a background to the interaction of wind and forests and how different factors affect the susceptibility of forests to damage. In the first section there is a discussion of the nature of airflow over forests, the detailed structure of this flow, and how the flow is affected by the forest structure and hills and mountains. The influence of these factors, in particular the structure of the forest at the landscape level, are discussed in terms of their consequences for the risk of storm damage. In the following section there is a description of the mechanics of wind damage and of trees as engineering structures subjected to wind loading, including the importance of the dynamic behaviour of trees. Finally, the various tree and site factors that affect the vulnerability of trees and forest stands to wind damage are introduced, which leads into the final section of the chapter. This final section discusses our understanding of the factors within the landscape and within forest stands that are known to affect forest susceptibility to damage. These include the influence of soil type, local topography, forest structure, tree species and forest management including thinning regimes. This knowledge is based on extensive and detailed statistical and mathematical analysis of damage to forests over many years, coupled with the long experience of foresters in adapting forests to the risk of wind damage.

In Chapter 3 the impacts of storm damage are described from an environmental, economic and social perspective. The initial section catalogues the enormous impact that storm damage can have on the carbon balance of forests. This is due to the loss of biomass accumulation in damaged trees, an increase in the breakdown of dead woody material in the forest, and the release of carbon dioxide from disturbed organic matter in the soil. These are important issues to be considered when carbon sequestration is embedded in forest management objectives and when reporting carbon sequestration as part of climate change mitigation strategies. The next two sections focus on the economic impact of storms, first from the perspective of the forest owner and manager, and then followed by the perspective of the wood processor. These sections also include discussion of the implications of storm damage for timber markets. They illustrate that economic consequences begin immediately following a storm with normally a sudden and abrupt drop in log price, and also that the consequences can last for decades if the level of damage is large. Although there may be a benefit of storm damage in the short term for some enterprises, such as harvesting operators required to clear the forest and nurseries providing plants to restore the forest, in general storms cause major disruption to markets and raw material supply over an extended period. The final section of this chapter discusses the impact of storms on society, a factor that is often not fully accounted for. These impacts can be direct, such as the loss of income for forest owners, or indirect such as loss of power or mobility due to trees falling on power lines, or the psychological and emotional impact of losing a forest one has grown up with. This section therefore reminds us of the importance of forests to society and the multiple services they provide in addition to timber production, and that we need to ensure we include the human dimension and our connection with forests at the centre of our thinking.

Chapter 4 is where the possibilities and requirements for action are considered. The first section sets the scene for the rest of the chapter. It starts with a discussion of the concept of risk mitigation within a classic risk management system, which requires a continuous process of evaluation and assessment before and after damage events. It then discusses the kinds of analyses of risk required, and the possible responses of risk acceptance, risk reduction, or risk sharing (e.g. through insurance). In the second section the role of forest management in controlling the level of damage is highlighted. It draws on the basic scientific understanding from Chapter 2 to illustrate what factors can be controlled through silviculture and what cannot be changed, and suggests possible approaches to forest management in areas particularly susceptible to wind damage. This section also presents the necessary management actions in preparation for storm damage and for regenerating forests if damage does occur. The subsequent section, in contrast, focuses on the immediate responses required following a storm. It deals with the alert phase that initiates contingency plans when a major storm is imminent, and the initial response phase immediately following a storm in order to restore basic infrastructure and operational capability. It finally addresses the recovery phase that sets in place the systems to restore the forest and the wood processing sector over the longer term. In the final section of the chapter the authors explore the issue of human perception of risk and how this affects our approaches to risk management in forests. Understanding these drivers is crucial if we are seeking an effective involvement of all stakeholders in ensuring the sustainability of our forests, and it provides a complement to the final section of Chapter 3.

The final chapter (Chapter 5) attempts to see into the future and to discover what is in store for us. It begins with the latest evidence on the impact of climate change and how this might affect the risk of wind damage. This includes both changes to the background wind climate and changes that might affect the vulnerability of forests directly. For example, forests might become more vulnerable due to changes in soil conditions (wetter and less frequently frozen soils in winter), due to increased tree growth because of raised CO_2 and N_2 levels, or due to the impacts of increased pathogen activity on tree health. The second section takes the latest predictions on the future of the European forestry sector in terms of wood production, wood demand and policy directions, and discusses how this might affect the impact of future storms, and what requirements this will place on policy makers and the forestry and wood processing sectors. It provides a vision of the framework in which forestry will be operating and leads into the final section of the book, which attempts to show the challenges for forestry in the 21st century. It reminds the reader that storms need to be seen as a fundamental part of the dynamics of natural forest ecosystems and how storms can present opportunities for foresters and planners to reassess their goals for a forest and the management approaches taken to realise these goals. It outlines what we can control and what we cannot, and discusses possible ways for dealing with the risk of storms including adaptive management practice and the sharing of the risk. Finally, we are reminded that storm damage must be considered along with all other forest disturbance agents and that only by working together at local, regional, national and supra-national levels will it be possible to develop resilient and sustainable forests for the overall benefit of society.

1.

Storm damage in Europe – an overview

Andreas Schuck and Mart-Jan Schelhaas

European forests have always been exposed to disturbances, as evidenced by reports for more than 600 years and fire marks found in trees and peatlands. They can be of abiotic (e.g. storms, fires) or biotic nature (e.g. insect infestations) being either of natural origin or human induced. From an ecological perspective they play a key role in forest ecosystem dynamics affecting stand structures and evolutionary processes linked to regeneration and succession. Their frequency, scale and intensity can vary greatly.

Less intense disturbances can allow for small scale gap dynamics which create a diversification of stand structure, stimulate natural regeneration, increase the amount of dead wood and modify micro-climate, thus having positive effects on biological diversity while economic damage stays within acceptable limits.

Storms and other disturbances are essential elements of the dynamics of natural forest ecosystems.

Disturbances can however be of more catastrophic nature affecting whole landscapes and the quality of wildlife habitats. They can, in the case of forests under management, strongly disrupt targeted goals, have severe consequences on wood production and timber markets and in some cases destroy the economic base for forest owners. They may seriously affect the provision of various goods and services including for example carbon sequestration, water balance and biological diversity.

Early observations on disturbances in forests are scarce. In the second half of the 19th century the number of reports increase, especially in countries in central Western Europe. After 1950 the coverage within Europe clearly increases, especially for fire and storms. However, the information is likely to not be complete and harmonised, since there is no monitoring system in place for Europe.

Accuracy and completeness of reporting on disturbance events is varied.

Box 1. Facts and figures of European forests.

- Forest and woodland cover more than one third of Europe's land area.
- Forests fulfil a wide range of vital services for society ranging from wood products and carbon sequestration to recreation.
- Forests are key reservoirs of biological diversity.
- Around 3 million people are directly employed in the forest sector.
- The forest sector has an estimated gross value added of €120 billion, contributing about 1% to the overall European GDP, and being as high as 3–5% in countries like Finland, Latvia and Sweden.

Scientific investigations estimate that about 0.12% of the standing volume of European forests is damaged annually (1950–2010 average) being equivalent to about 38 million m^3/year. This represents approximately the annual fellings of Poland. The damage to forests is due to a multitude of disturbances. For abiotic damage, wind is the most prominent. It is responsible for about 51% of all recorded damage. Wildfires follow with 16%, snow 4% and other abiotic damage with 6%. Biotic damage adds 17% and is mainly caused by bark beetles. The remaining 6% are either combinations of damage or cannot be directly accounted for.

When looking at the total forest area in Europe affected by biotic and abiotic damages, recent published data estimates it to be at about 7.3 million hectares or 5.8%. In terms of forest area the most prominent damaging agents are insects and diseases, wind, and wildlife and grazing.

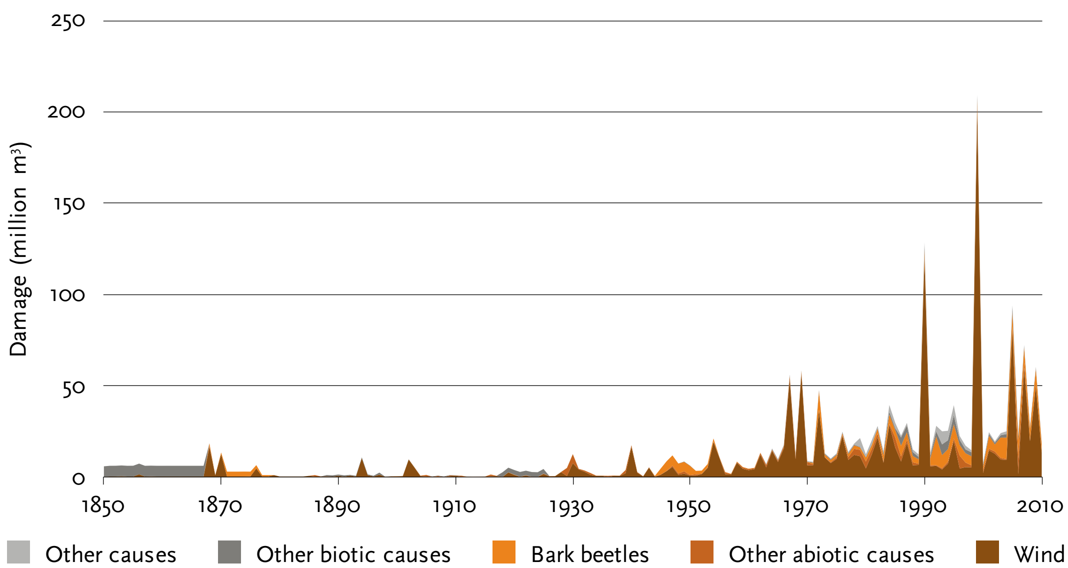

Figure 1. Total damage occurring in European forests (million m^3) due to different disturbances. The category "other causes" includes anthropogenic damage, unidentified causes and mixed causes. (modified from Schelhaas 2008).

A storm is an atmospheric disturbance manifested in strong winds, often accompanied by rain, snow, or other precipitation and also by thunder and lightning.

Observations across Europe show that disturbance damage to forest has increased markedly in the last few decades (Figure 1). Recent changes in climate are frequently stated as a major driving force behind such increases. However, especially for storms it is very difficult to statistically prove trends in frequency and severity, because data series are relatively short, usually inhomogeneous, and storms are highly stochastic.

Scientific literature therefore gives a diverse picture for storms: some results indicate an increase of maximum gust wind speeds at local level while others show a decrease in cyclone frequency over the last few decades. However there is evidence that the actual severity of storms in the wake of climatic changes may increase during the next decades.

Storms are highly stochastic and relatively rare events. It is thus very difficult to prove trends from short time series of meteorological observations. There is some evidence that climate change will increase the severity of storms in the next few decades.

Forest management activities can have noticeable influence on forest susceptibility to disturbances. Research suggests that forest management may have contributed in the same order of magnitude to the disturbances increase in Europe as climate change. In particular the steady increase of the forest area and growing stock and the increase of the average forest age may have contributed to an increased susceptibility of forests towards storm damage (Figure 2).

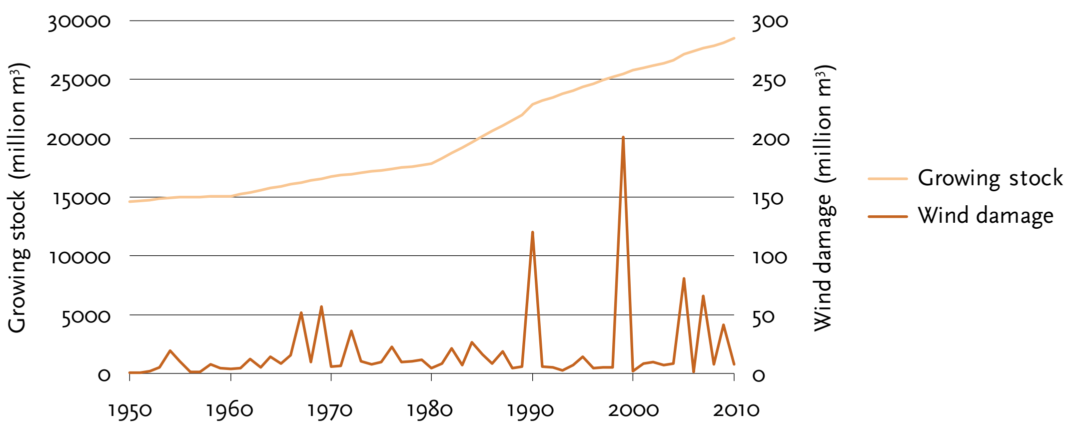

Figure 2. Development of growing stock and damage caused by storms in the period 1950–2010.

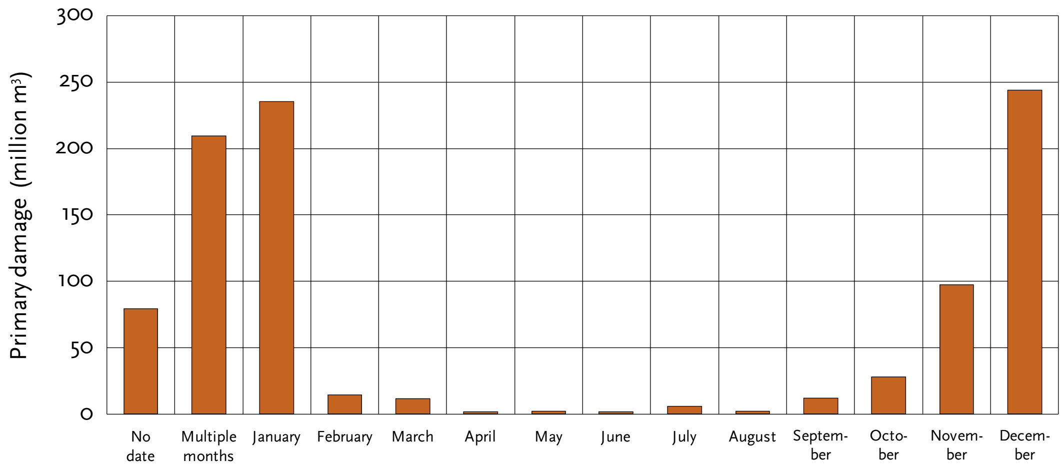

Figure 3. European storm damage to forests by month of the year. (Gardiner et al. 2010)

Management activities can significantly influence forest susceptibility towards storms as well as other disturbances.

Storm damage in forests can originate from different types of weather systems. For example, thunderstorms can be accompanied by severe wind gusts, tornadoes and/or downbursts. However, these usually occur in summer and can cause heavy damage, but at a limited spatial scale of hectares to at most a few km^2.

Extra-tropical cyclones, however, can generate high wind speeds affecting several thousands of km^2. They usually occur in winter, when temperature differences over the northern hemisphere are most pronounced. They are often associated with various types of heavy precipitation, like rainfall, ice, hail or snow. These winter storms produce most of the damage recorded in Europe (Figure 3), not only to forests, but also to infrastructures and private property. In this report we will focus on winter storms and their effects.

Extra-tropical cyclones build up their strength over the North Atlantic Ocean and weaken when they make landfall. Usually they follow a track over Northern Britain, heading for Germany or into Scandinavia. If the northern route is blocked by a high pressure system over Northern Europe, more southward tracks are possible as well.

Since 1950 more than 130 storms have been recorded causing notable damage to forests in Europe with on average two destructive storms each year. Figure 4 illustrates the storm tracks for a selected number of prominent storm events in Europe dating back to the early 1950s. Figure 5 provides a rough estimate of the geographic area in which the corresponding major damage to forests occurred. The Western coastlines are most exposed, with reported damage covering an area from France and the Southern Alps up to Southern Scandinavia. In some cases damage reports extend as far as the Baltic States and the Russian Federation.

Spatial distribution of wind storms in Europe is concentrated on Western and Central Europe but also becoming more frequent in Northern Europe.

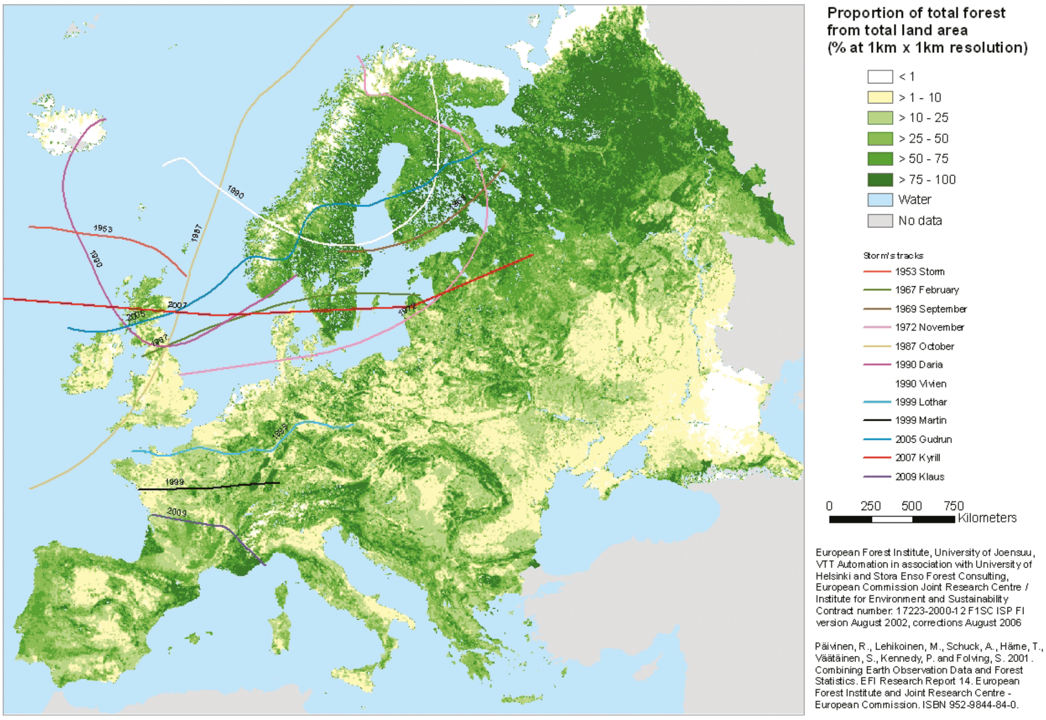

Figure 4. Paths of low pressure centres for selected storms. Most storm tracks derived from NASA re-analysis of extratropical storms (adapted from Gardiner et al. 2010)

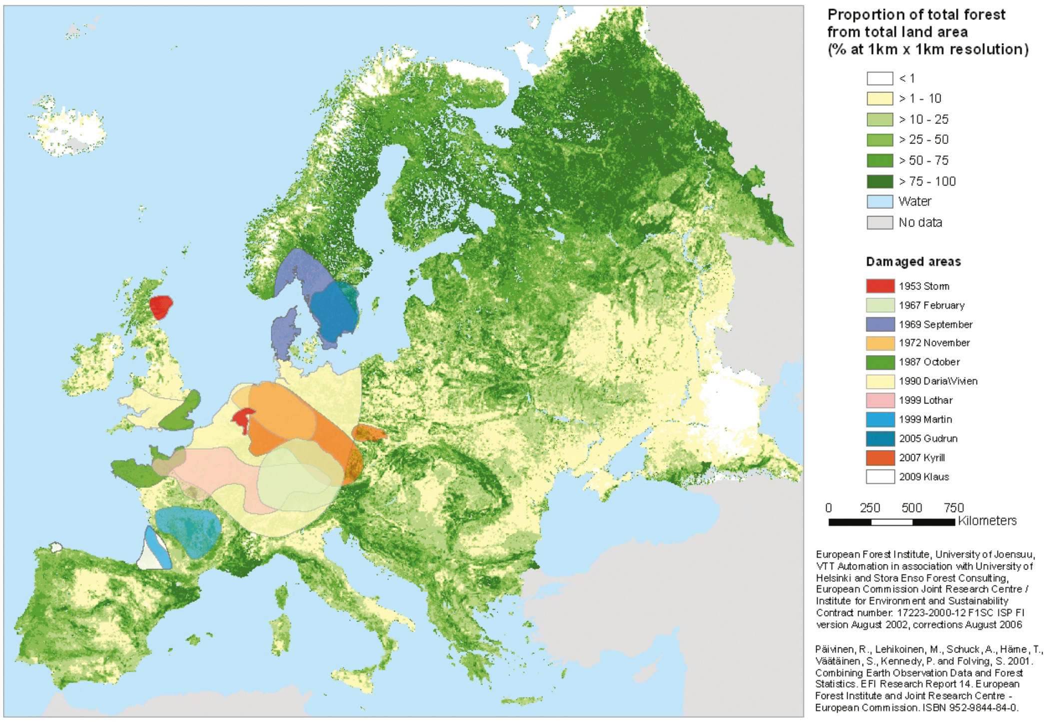

Figure 5. Estimated areas affected by selected storms (adapted from Gardiner et al. 2010).

Figure 6. Storm damage in Les Landes, France following the storm of January 2009 (photo: ©DRAAF Aquitaine)

In order to illustrate the devastating forces of such events and their long term implications, two examples of catastrophic storms are briefly presented.

In December 1999, storms *Lothar* and *Martin* turned out to be the most destructive storms to European forests on record. More than 240 million m^3 of timber were damaged across 15 countries. This is equivalent to an about 34 km high wood tower of timber stacked on a football field. France was worst affected with 176 million m^3 of damage followed by Germany with 34 million m^3 and Switzerland with 14 million m^3. The damage in France represented 3 times the annual harvest of wood.

Beside the catastrophic effects of storms to forests, huge damage was caused to buildings, infrastructure and transport systems with the total insured losses put at more than €10 billion. Severe flooding occurred along the French coast. In total more than 140 people were killed in Europe, 88 in France alone. In the year 2000, 100 forest workers were killed in France during wind damage clearing operations.

Insect attacks further increased damage to forests in the following years mainly in France, Germany and Switzerland. Timber prices fell noticeably as a consequence of the storm events with an estimate of €6 billion lost in revenue in France alone.

The damaged timber resulting from the 1999 storms Lothar and Martin are equivalent to a wood tower of about 34 km height stacked on a football field!

Figure 7. Damage to infrastructure caused by a wind storm (photo: Ken Schulze / shutterstock.com).

In mid-January 2007 storms *Kyrill* and *Per* tracked across Central Scandinavia and Central Europe respectively. They resulted in a total of 59 casualties and were responsible for massive disruptions to communication and electricity supplies. An estimated 12 million m^3 of timber was severely damaged by Per, mainly in Sweden. About 54 million m^3 were reported to have been damaged due to Kyrill across Central Europe most prominently in Germany, Czech Republic, Poland and Austria.

Insured losses from the storm Kyrill were calculated at €4.5 billion with about €2.4 billion in Germany alone. Forest industry in Germany reported about €1 billion in lost revenue in addition to the direct damage caused by the storm.

After strong windstorms and their severe damage to forests a change of mind-set towards planning for and response to storm events has often taken place in the past and will need to continue to take place now and into the future. During the last few decades the financial instruments and the effectiveness of response has developed in most storm affected countries in Europe as well as at the European Union level itself (see also Chapter 5.3). For example, in the United Kingdom following the severe wind damage from storms in 1953 and 1968 the risk of wind damage became an integral part of forest management. All areas of forest were given a hazard rating that indicated at what height trees were likely to be damaged and a wind classification map illustrated where thinning was

Figure 8. 1 million m^3 of wood stacked on an abandoned airfield in Southern Sweden (photo: Ola Nilsson).

too risky to undertake. In the Netherlands following the storm in 1973 new plans were drawn up for the State Forestry areas damaged by the storms, giving particular attention to the structure and stability of the forest and increasing the proportion of broadleaved tree species. Such changes in thinking and approach to management have continued in countries such as Germany and France that were badly affected by storms in 1999 and 2007 and in 1999 and 2009 respectively, leading to an increase in the amount and availability of up-to-date guidance for forest managers, and the development of improved infrastructure, such as wet storage areas for storing timber after a storm. Such continued re-evaluation and adaptation to the threat of wind damage needs to be a continuous part of the thinking in the forest sector and is discussed in more detail in Chapter 4.1. We hope this book will support that process to be undertaken by providing a detailed background to the best current understanding of storms, their impact and potential ways to mitigate the risk of damage.

Recommended reading

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2.

Susceptibility to Wind Damage

2.1. Airflow over forests

Yves Brunet

Key terms

Aerodynamic drag: Drag due to pressure differences around different parts of a tree (leaves/needles, branches and stem).

Boundary-layer: The part of the atmosphere closest to the earth's surface and which directly feels its effect. Can vary in depth but is generally of the order of 1 km.

Coherent structures: Organised rotational motions in the air.

Kelvin-Helmholtz instabilities: Waves and subsequent instabilities that can occur when there is velocity shear (see below) in the atmosphere.

Momentum flux/transfer: The transfer of momentum in the wind flow to the earth's surface due to turbulent exchange. The momentum transfer is higher over aerodynamically "rough" surfaces such as forests than over "smooth" surfaces such as grass or water.

Plane mixing-layer: A layer where two co-flowing airstreams mix. It is the flow pattern characteristic of forests where there is slow moving air inside the forest mixing with faster moving air above the forest.

Turbulent kinetic energy: The mean kinetic energy of eddies in a turbulent flow. A measure of how much energy is contained within the turbulent part of the flow.

Vortices: See Coherent structures.

Wind shear: Change of wind speed with height. Usually greatest just above the top of a forest.

Wind load on trees primarily depends on the local characteristics of the wind field, in conjunction with tree architecture and foliage density. Wind damage may occur when the instantaneous wind load exceeds some threshold. A good description of wind dynamics in forest canopies is therefore required in order to understand the causes of forest storm damage. Rather than focussing on mean wind fields, special attention has to be paid to the behaviour of turbulence in forested areas because trees usually fail under the action of wind gusts rather than the mean wind load. The recent development of powerful computer-based simulation tools has contributed to a better understanding of canopy turbulence and the means to analyse turbulent flow in complex, three-dimensional environments.

In a horizontally homogeneous canopy (flat and continuous) it is now well established that turbulence is dominated by intermittent, energetic downward-moving gusts. Such coherent structures, controlling most of the momentum transfer between the atmosphere and the vegetation, are particularly important for understanding wind damage. They have been described as hairpin-shaped vortical structures or "double-roller" vortices with a downwind tilt from the horizontal. At canopy top for example, these structures extend over typical distances of 10, 3 and 2 h (h being the canopy height) in the streamwise, vertical and spanwise directions relative to the wind, respectively, with a slope angle to the horizontal of 18°.

Coherent structures

The exchange of momentum and energy between the atmosphere and a forest canopy is dominated by coherent canopy-scale structures. These structures are responsible for the strongest wind loading on trees.

Observations have shown that the atmospheric flow near the top of a vegetation canopy is analogous to a plane mixing-layer flow. The characteristic inflection point in the mean velocity profile at canopy top is responsible for the initiation of transverse Kelvin-Helmoltz type instabilities, which develop into large, three-dimensional coherent eddies elongated in the streamwise direction (Figure 9). The mean longitudinal separation in the wind direction between adjacent coherent structures is a linear function of the mean velocity at canopy top divided by the wind shear (change of wind speed with height) at canopy top ($L_s = U_h/(dU/dz)_h$).

This general picture of turbulent flow over plant canopies has been observed over a wide range of cases, from wind-tunnel models to crops and forests. The relationship between the longitudinal separation of gusts and the wind conditions at canopy top holds over a wide range of canopy densities, provided that the plant area index (total vegetated surface area per unit ground area) is larger than a threshold (of the order 0.5 to 1). As canopy density decreases below this threshold, the flow progressively loses the characteristics of a plane mixing layer and evolves towards a boundary-layer flow with immersed, isolated trees. In such sparse canopies, the inflection in the mean horizontal velocity disappears or becomes too weak to sustain the instability process responsible for the generation of mixing-layer eddies.

In the real world forest plots are of finite size and limited by edges. Behind upstream edges the flow adjusts progressively to new conditions depending on the canopy charac-

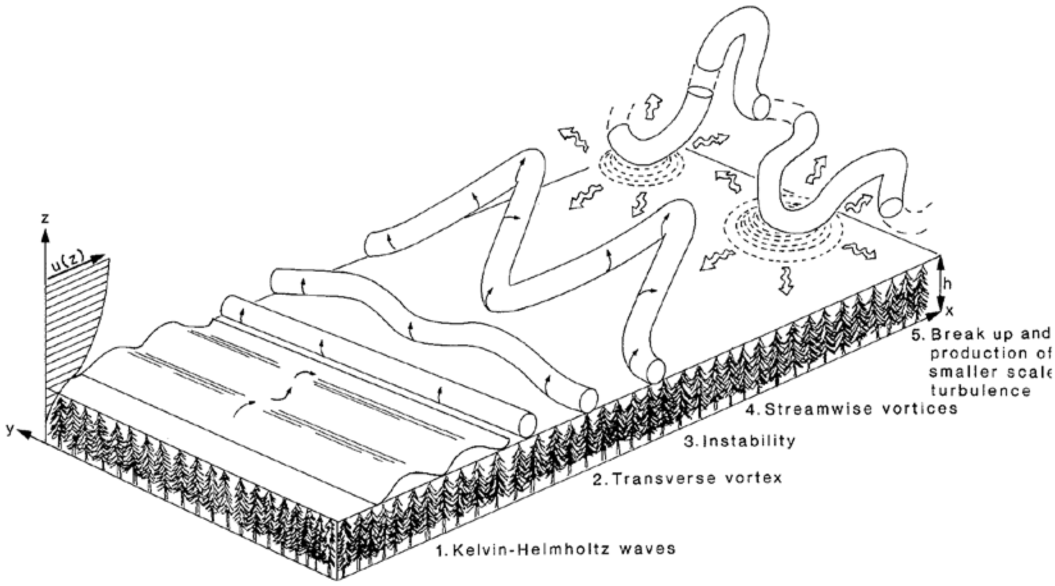

Figure 9. Schematic diagram showing evolution of canopy-scale coherent structures (after Finnigan and Brunet 1995).

teristics. It is important to study this transition region, where the nature of the flow is less well known than in homogeneous canopies, because in many forested areas the limited size of forest plots results in edge regions occupying a significant fraction of space.

When the wind enters a forest plot it accelerates just above the canopy top and decelerates in the whole layer occupied by plant elements through the action of aerodynamic drag. This creates an inflection in the mean horizontal velocity profile and sets up a shear layer at canopy top. The thickness of the shear layer, which determines the scale of the most energetic canopy eddies, is rather modest in the edge region but it quickly increases further downstream as the internal boundary layer grows.

In the canopy region where the mean horizontal velocity decreases with distance from the edge, the mean vertical velocity is positive, and transports low turbulence levels from the lower canopy to its upper layers. In the upper canopy this low turbulence air meets external boundary-layer structures from above generating a region of reduced turbulent kinetic energy but large velocity variation, typically located at $2.5\ h < x < 6\ h$ (where x is the distance from the edge). This region, sometimes referred to as the "enhanced gust zone", or EGZ, is characterized by intermittent, energetic sweeps, in an otherwise relatively quiet portion of the flow. Along with the fact that trees at established edges develop stronger root anchorage, this may account for observations that damage due to windstorms usually occurs at some distance from the edge rather than right at the edge (Figure 13). Whether or not the EGZ is a region particularly prone to higher damage risk than further upstream or downstream is still a matter of debate.

Forest edges

There are large changes to the nature of the airflow at the edge of a forest and trees a few tree heights back from the edge appear more vulnerable to wind damage than trees in other parts of the forest. Multiple forest edges in heterogeneous landscapes can enhance the general level of turbulence but the exact shape of the edge does not appear to have much influence on the flow structure and wind loading.

The vertical transport of low turbulent kinetic energy is also responsible for a delay, or a horizontal shift, in the development of canopy turbulence, as compared with the rate at which the mean flow adjusts downstream of the canopy edge. The latter occurs within the first canopy heights downstream of the edge, but it takes about 9 h for the mean vertical velocity to vanish. Just behind the edge the canopy flow is similar to the upstream flow with turbulent structures penetrating the canopy almost horizontally and being partly deflected upwards. Momentum transfer is dominated by outward rather than inward motions. Further downstream, between 3 and 5 h from the edge, the shear layer becomes close to equilibrium inducing the formation of transverse vortices. These roller structures are destabilized by secondary instabilities leading to the formation of counter-rotating streamwise vortices, which in turn evolve towards complex three-dimensional coherent structures. This formation process is completed at about 9 h from the edge, where these structures can start to efficiently transport momentum through a series of sweep events. These stages of development occur closer to the edge with increasing canopy density, and much further from the edge with canopies having a deep and sparse trunk space such as typical mature pine forests. The shape of the upstream edge has been shown not to have any significant effects on the canopy flow.

All the above considerations apply at the scale of homogeneous plots. In actual landscapes the forest may be fragmented into many such plots, and the terrain itself may not be flat. Flow over topography and flow over multiple edges are topics of particular interest since they may introduce external effects and alter the ideal picture sketched so far.

Multiple edges have been known for a long time to generate a regional roughness that may increase the amount of turbulence in the atmospheric boundary layer. Another effect is that in a fragmented landscape most forest plots are in the wake of plots upstream and therefore face an accelerating flow in which the turbulent kinetic energy created upstream is being redistributed vertically. Depending on the canopy height, the streamwise extent of the forested plots and the size of the open areas in between, the combination of these effects may create regions where turbulence intensity and the momentum flux reach a maximum before they decrease further downstream. The relative size of the open areas between forest plots may therefore modulate the turbulent regime that affects the downstream plot. Recent unpublished results on flow over small forested plots separated by clearings of various sizes have shown that turbulent kinetic energy and mechanical strains exhibit a peak for a clearing length about twice the plot length, whereas small clearings seem to reduce the intensity of the EGZ. The influence of the fragmentation level on the amount of turbulence in the lower atmosphere clearly requires further study.

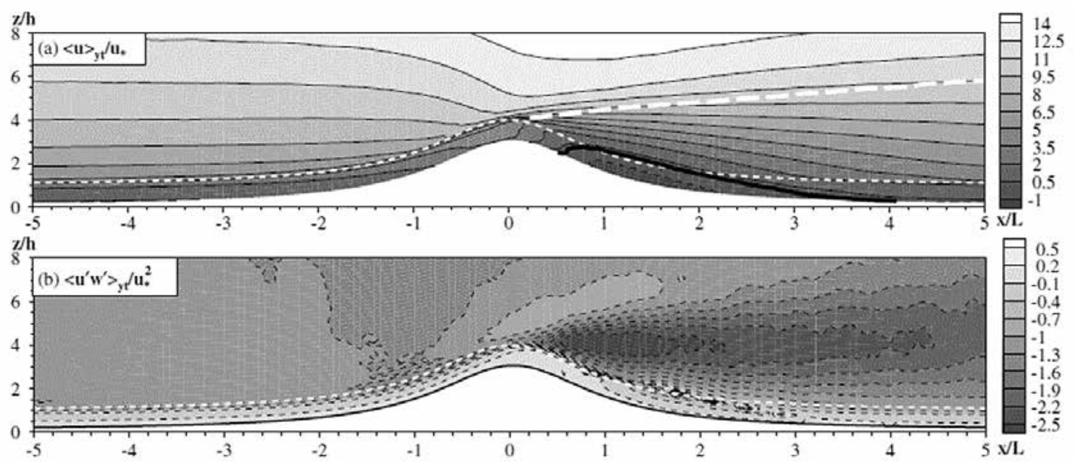

Figure 10. Wind speed and momentum flux variation across a forested hill (after Dupont et al. 2008).

Flow over hills

At the top of the upwind slope of a moderately steep forested hill there may be particularly deep penetration of gusts into the canopy. Behind the hill top there is an area of quieter flow followed by an area of much gustier and potentially damaging conditions towards the bottom of the downwind slope.

Little work has been carried out on flow dynamics over forested hills. A recent investigation on a hill of height-to-width ratio of about 1/3 (Figure 10) has shown that in the upper third of the upwind slope of the hill the turbulent structures penetrate deep into the canopy, whereas on top of the hill only the upper part of the vegetated layer is well coupled with the atmosphere above, primarily through the action of the transverse coherent motions discussed above. Just behind the ridge a quiet region occurs but further downstream turbulence becomes much more active and intermittent, with strong sweeps and occasional recirculation. The maximum-to-mean ratios of tree displacement and mechanical stress may be particularly high in the lower half of the downwind side of the hill.

The progress made over the past twenty years on understanding and modelling canopy turbulence provides a relevant framework for the analysis of wind risks to forests. This is particularly true at the scale of homogeneous stands and single discontinuities such as edges, which have received most attention. The complex fluid mechanical interaction between the atmosphere and trees within the forest should now be considered at larger scales, where forests are often fragmented and where topography may significantly alter the standard model for canopy flow. In this perspective simulation tools coupling tree motion with wind dynamics at the scale of heterogeneous landscapes should be of great help. Recent attempts have provided encouraging results and will continue to be developed in the coming years.

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2.2.

Mechanics of wind damage

Heli Peltola, Barry Gardiner and Bruce Nicoll

An improved understanding of the mechanisms of wind-induced damage is of interest to many forest ecologists, but also crucial for managers of forest resources in order to make appropriate silvicultural decisions related to risk management.

Mechanical behaviour of trees

The susceptibility of individual trees and tree stands to wind damage, and the mechanism of wind damage, is controlled by the properties of the wind climate (wind speed, duration and gustiness as discussed in Chapter 1 and Chapter 2.1), forest structure (e.g. fragmentation, even-aged/uneven-aged) and tree/stand characteristics (e.g. species, height, diameter at breast height, crown and rooting characteristics and stand density), and site conditions (e.g. soil type and topography). In addition, the forest management (e.g. spacing, thinning, fertilization, final cutting) of a stand and neighbouring stands can affect the susceptibility to damage (this is discussed further in Chapter 2.3).

The mechanism of wind damage can be studied by the use of static and dynamic tree pulling tests, tree sway and wind speed measurements, wind tunnel studies, and mechanistic modelling. The use of mechanistic modelling also makes it possible to define causal links between different factors and tree stability and to estimate the critical wind speeds needed to uproot and/or break individual trees within a stand.

Figure 11. Norway spruce stem snapped in strong winds (Photo: Chris Quine, Forest Research, Roslin, United Kingdom)

Static: Steady or only slowly varying (minutes)

Dynamic: Fluctuating and changing at a frequency close to tree natural frequency (0.1 – 10 s)

MOE: Modulus of Elasticity. A measure of material flexibility

MOR: Modulus of Rupture. A measure of material strength

Resonant or Natural Frequency: Frequency at which a tree oscillates naturally if displaced and released

Mechanical Transfer Function: Measure of efficiency of energy transfer from the wind to a tree as a function of frequency

Hinge Point: Point on the ground on the downwind side of the tree where the roots upwind are raised and those downwind are depressed during a storm. The point about which the tree-root system rotates.

Critical Wind Speed: The canopy top wind speed at which damage is predicted to occur to a tree. A decreasing critical wind speed equates to increasing vulnerability of the tree.

Based on fundamental physics, a tree could be assumed to bend (as a function of the stem wood MOE) to a point of no return under static wind loading, if a constant mean wind speed and direction are assumed. In such conditions, the mechanical stability of a tree is affected by the horizontal force due to the wind and the vertical force due to gravity, taking into account the weight of the overhanging stem and crown (including any additional snow loading). Consequently, the resistance of a tree to uprooting depends on its anchorage, whereas the resistance to stem breakage (Figure 11) depends on the strength of the stem wood (MOR). A tree is expected to fail if the applied bending moment of a tree exceeds the maximum resistive moment provided by the roots or stem. In reality, trees sway dynamically as a response to wind gusts. Furthermore, tree crowns are streamlined and expose less area in windy than under calm conditions. These factors all need to be taken into account, when estimating the critical wind speeds required to cause wind-induced damage (Figure 12).

In response to dynamic wind loading, trees sway with short-term (few seconds) oscillatory motion. This leads to increased bending of tree stems and bending moments on the stems and root systems of trees compared to those calculated from static wind loading analysis alone. To increase tree stability, trees having lower height to breast height diameter ratio, with higher natural (and resonant) frequencies, should be favoured in thinning. This is because the peak energy in the turbulent wind is typically at lower frequencies than tree natural frequencies.

Dynamics, tree sway, resonance, tree response

In response to dynamic wind loading, trees sway with an irregular swaying pattern, with consequent short-term (few seconds) oscillatory motion. This increases the bending of tree stems and imposes larger applied bending moments on the stems and root systems of trees than those based on static wind loading calculations. This phenomenon is emphasized when the pattern of wind gusts becomes coupled with the natural swaying frequency of the trees. Under damaging conditions, trees have been found to be blown down or broken at considerably lower mean wind speeds (in some cases as low as 10 ms^{-1} at canopy top) than the wind speeds predicted from static tree pulling tests under calm conditions.

The estimation of the mechanical transfer function of a tree provides the means to study tree response to dynamic wind loading. It can also reveal the efficiency of energy transfer at different frequencies and provide information on the amount of damping in the system. The peak frequencies in tree response coincide with the estimated natural sway frequency of trees. Higher order peaks can also be observed, in particular, for slender trees in dense stands. In general, trees show maximum bending during their first cycle, after which they return to their rest position after a few oscillations due to damping. However, failure of stem or root anchorage will occur if the applied bending moment exceeds the resistive bending moment for tree anchorage or stem strength. Cumulative failure can occur over many cycles or maybe even over a period of months or

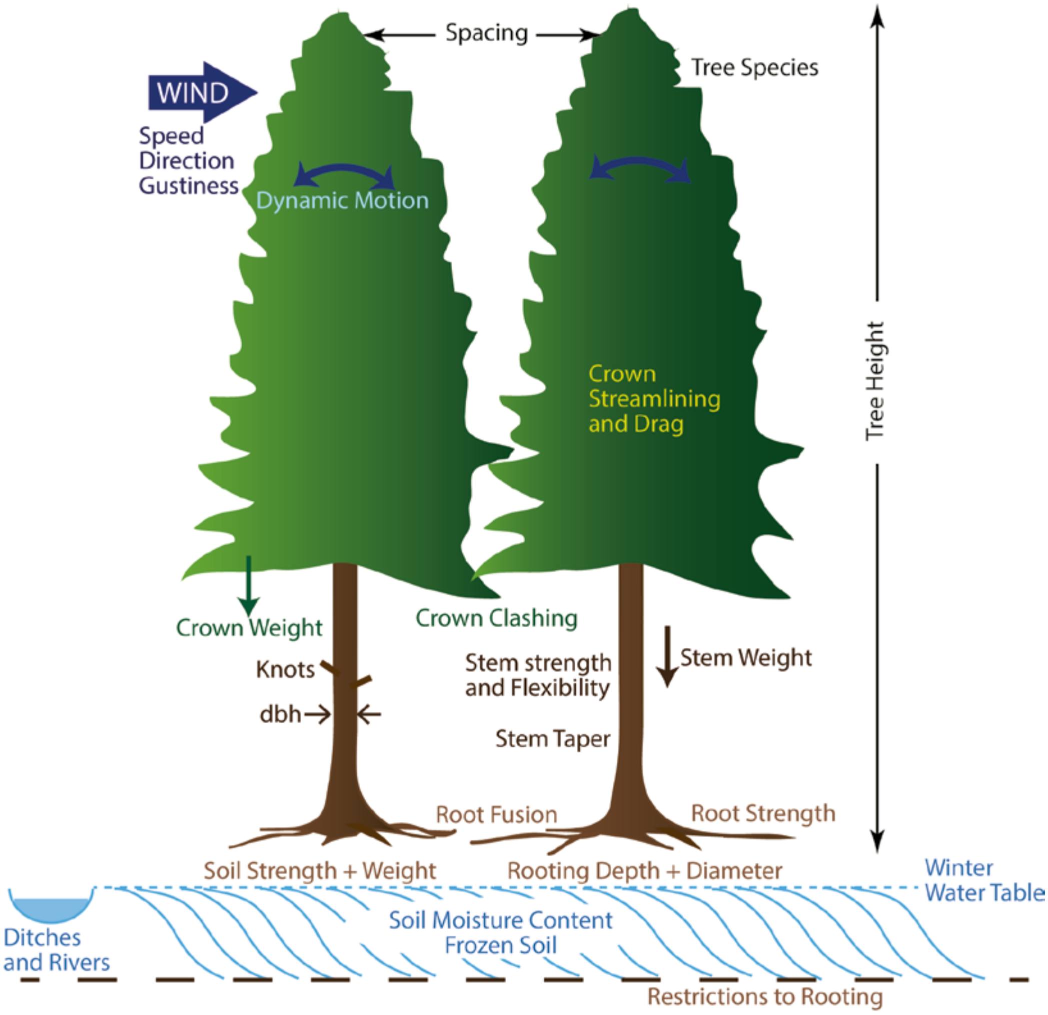

Figure 12. Factors influencing the vulnerability of trees to wind damage (critical wind speed). Courtesy of Kana Kamimura.

years. There is also some evidence that resonant swaying motion results in even larger applied bending moments than those expected based on individual gusts alone so that trees with resonant frequencies close to the peak in wind energy are particularly at risk. In order to reduce wind risk to trees, the characteristic frequencies of the primary motions of trees should be raised, which means that, for example in thinning, the trees having lower height to breast height diameter ratios and consequently higher resonant frequencies should be favoured for retention. However, after thinning the higher wind turbulence over the thinned stand leads to larger energy transfer to the trees at their new wider spacing and increases their swaying and wind loading. This increases the risk of wind damage until the trees acclimate to their new environment over a period of a few years.

As a result of wind loading uprooting or stem breakage of a tree may occur if the maximum applied bending moment due to the wind and to the overhanging mass of the tree is larger than the resistive bending moment that can be provided by the root system and the stem. The wind speed at which damage is predicted to occur is called the "critical wind speed".

Rooting resistance, stem bending, stem resistance to breakage

The resistance of a tree to uprooting has typically been estimated by pulling trees over with a winch and cable system, and by determining regressions between the maximum applied bending moment and various tree physical characteristics such as stem weight or combinations of variables such as tree height and breast height diameter (e.g. $\propto$ *height* × *dbh*^{2}), considering the results separately for each combination of species and soil type. The resistance of a tree to uprooting can also be estimated indirectly based on various components of root anchorage including the root/soil plate weight, the strength of windward roots, the strength of the root hinge, and the soil strength at the base of the root/soil plate. The failure of root anchorage is especially likely if the centre of gravity of a tree moves past the hinge point of the root system.

The estimation of the resistance of tree stems to stem breakage is usually based on the assumption that the wind induced stress in the outer fibres of a tree stem is constant at all points between the base of the canopy and the butt swelling at the stem base (this is not strictly true in general). A tree stem is assumed to break if the total maximum applied bending moment (from the wind and overhanging weight of the tree) exceeds the stem resistance calculated from the breast height diameter and the modulus of rupture of the wood (MOR). The relative strengths of the stem and roots determine the mode of failure.

Estimation of critical wind speed

Increased understanding of the behaviour of trees in strong winds and the mechanisms of root anchorage and stem resistance have made it possible to develop mechanistic models, which allow the calculation of the critical wind speed (hourly average wind speed at canopy top) needed to uproot or break a tree. They also allow evaluation of the effects of forest management on tree stability, and even to define appropriate management strategies for reducing wind-induced risks to forests. This would not be possible with purely statistical approaches because such approaches do not provide causal links between different forest and tree characteristics and tree stability.

Mechanistic models typically use a static approach to model wind forces with the turbulent aspect of wind taken into account through the use of a gust factor, which increases the maximum wind loading experienced by a tree. This gust factor has been estimated as a function of tree height, tree spacing, distance from the upwind stand edge and the size of any upwind gaps. In addition crown streamlining (reduction of the drag area) due to the wind has been included in mechanistic models, utilizing the findings of wind tunnel experiments. However, dynamic swaying of trees due to gusts has not yet been fully incorporated and such mechanistic models seldom consider the support provided by crown and rooting contacts with neighbouring trees in a stand. Another major omission is that most mechanistic models are unable at present to deal with the risk to individual trees within the forest, which is a major handicap for understanding the risk to complex multi-layered forests.

The critical wind speeds needed to cause uprooting or stem breakage of trees are predicted to decrease as tree height, the ratio of tree height to breast height diameter, or between tree spacing increases. In addition, the trees at newly created upwind edges of a stand are expected to be much more vulnerable to damage than trees well inside a stand or at permanent or long established edges. At the same time, trees inside stands

Figure 13. Wind damage inside a stand of Sitka spruce with a long established edge (Cumbria, North-west England). Notice that the edge trees are undamaged. (Photo: Graeme Prest, Forestry Commission, United Kingdom)

with long established edges (Figure 13) are more vulnerable than trees at the edge (see Chapter 2.1 for a discussion on turbulence development at edges).

Adaptation to wind loading

A major difficulty for calculating the risk to forests is a lack of understanding of how quickly trees can acclimate to changes in wind conditions, for example due to forest clear cuts, thinning, road construction or other disturbance. Following any increase in wind loading trees are known to respond gradually, first by increasing the allocation of assimilates to the roots, and then followed by an increase in stem taper in order to increase their mechanical resistance. What is not known is how quickly this acclimatisation to the wind takes place and how dependent it is on site fertility, tree growth rate and/or tree age. Our best estimate based on measurement of tree response to thinning and gap creation is that this takes place in most cases within a period of between 5 to 10 years.

Understanding of the interactions between trees and forest stands makes it possible to define the critical wind speeds needed for wind damage at tree, stand and regional level, and how these change with time.

Interactions between trees within stands

The most obvious beneficial effect of trees on one another within forests is at the forest edge, where trees, conditioned by increased exposure to the wind act to protect the interior trees. If the trees at the edge are removed through felling or by wind damage the trees at the new edge, which were previously unexposed, become very vulnerable to damage. It is also known that canopy clashing can be important by damping tree swaying and reducing the immediate impact of the wind so that trees in close proximity to each other provide mutual support. However, in dense stands where crowns are in contact, if a tree falls or breaks, the vulnerability of the surrounding trees will be increased proportionally more than in widely spaced stands (i.e. the critical wind speed will be reduced more). There is also some evidence that the presence of smaller sub-canopy trees in multi-storey stands may reduce the wind loading on the main canopy trees, either through direct support from the smaller trees and an effective increase in the damping of the larger trees, or by a more distributed absorption of energy from the canopy-penetrating gusts. At the same time the interlocking of roots between trees can provide additional stability benefits by giving each tree a much larger effective root plate.

Interactions between neighbouring stands

The exact structure of the forest and the type of ground upwind of a particular forest stand markedly affect the mean and turbulent wind conditions (see Chapter 2.1). It is well known that felling of adjacent stands or construction of roads can have a large impact on the vulnerability of a forest because of the increase in wind speed that occurs within the new gap. The larger the upwind gap the larger the increase in wind loading on the forest downwind of the gap because of the increased fetch over less rough ground. In addition, if clear felling creates a funnelling effect into the corner of the felled area or squeezes air between two forest blocks damage is more likely to occur. There is also some evidence that particular patterns of forest and open ground may contribute to increased levels of turbulence compared to more homogeneous forest.

Interaction of site conditions, forest growth and dynamics and managements

For long term risk assessment at stand or regional level it is necessary to couple detailed knowledge of site and forest stand characteristics with tree growth, wind damage and airflow models, and future wind climate predictions. Input information on forests at fine resolution (individual trees) over very large areas (whole forests and even countries) is now becoming routinely available through satellite and aircraft based remote sensing. This means that vulnerability (critical wind speeds) can now be evaluated at the level of individual trees for whole forests and regions by combining details of tree and stand characteristics in mechanistic wind risk models (see Figure 29 for an example of critical wind speeds calculated across Europe). When combined with wind climate data from meteorological stations, airflow models and/or climate models it is possible to calculate the probability of damage now and into the future. However, it needs to be remembered that predictions will tend to be more accurate as the scale increases, so that forest scale risk predictions will be more accurate than those at the individual stand level, and these in turn more accurate than predictions of the risks to individual trees.

Conclusions: The exact mechanism of failure in trees subjected to wind loading is a function of various tree, stand and site factors. These factors define the critical wind speed or vulnerability of trees in the forest. However, the local wind climate, the exact forest structure and the local topography will determine the probability of such winds occurring at a particular location (see Chapter 2.3).

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2.3.

Influence of stand characteristics and landscape structure on wind damage

Marc Hanewinkel, Axel Albrecht and Matthias Schmidt

Introduction: Key factors influencing vulnerability to wind damage

The risk of wind damage to forest stands is mostly a combination of wind climate (e.g. average and gust wind speed and wind direction: see Chapter 2.1), tree and stand characteristics as controlled by silvicultural management, site characteristics and factors increasing stand exposure (see Chapter 2.2).

Two widely acknowledged predisposing factors for storm damage are tree species and tree or stand height. Other important characteristics influencing wind damage risk to individual trees or forest stands are the relation between the tree diameter and tree height (referred to as h/d-ratio), crown length, root rot, stand density and structure. Other site related characteristics of importance include exposure (e.g. topography, upwind clear cuts), aspect, slope, water regime and soil texture. Tree and stand characteristics appear to have more impact on tree and stand vulnerability than site characteristics.

Tree species

Tree species can have a noticeable effect on vulnerability towards storm damage. Comparisons with respect to tree species are limited since no approach is currently available that covers the entire variety of species groups. However, statistical analyses of damage suggest that conifers are more susceptible to damage than broadleaves because of the higher drag of the evergreen coniferous forests during winter storms when broadleaved species are leafless. From an analysis of damage caused by the storm "Lothar" there was found to be a decreasing probability of storm damage to single trees from Norway spruce, which was the most vulnerable, to Silver fir/Douglas fir to European pine/larch, beech/oak and other broadleaves, which were the least vulnerable (see Figure 14). In Scandinavia the probability of damage was found to decrease from Norway spruce to Scots pine to birch. A similar ranking of species has been found by a number of researchers including following analysis of the severe storms in December 1999 in France (see Table 1 in Chapter 4.2). These analyses suggest that in general poplar and spruces appear to be amongst the most vulnerable and Silver fir, European pine, beech and oak amongst the least vulnerable species. However, very recent studies suggested Douglas fir is as vulnerable as Norway spruce, so it is important to realise that species

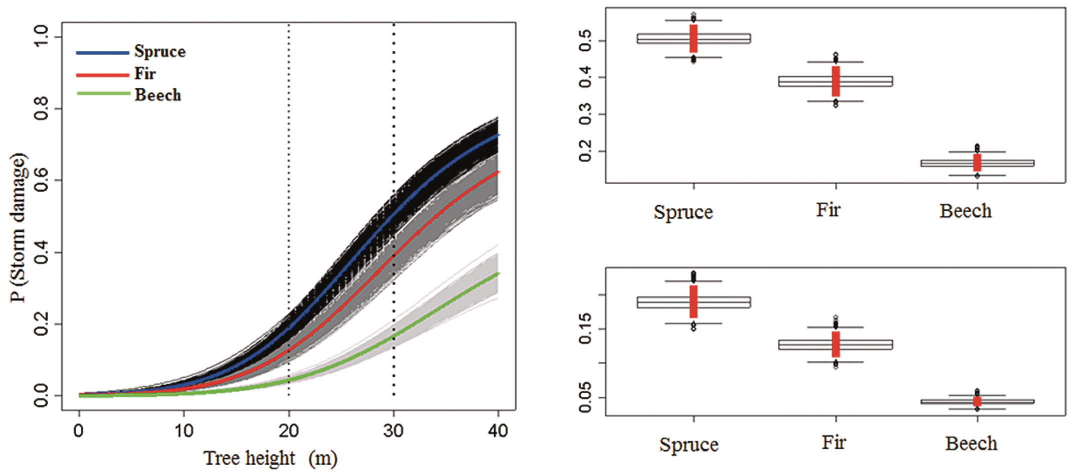

Figure 14. Damage probability for different tree species from analysis of damage in storm Lothar.

differences are not yet fully quantified and the exact order of species vulnerability is not certain and probably depends on location and soil. As always planting species adapted to the soil and climate of a location should be a priority.

Species differences

Spruces and poplar appear to be among the most vulnerable to storm damage and Silver fir, European pine, beech and oak among the least vulnerable.

Tree height and related parameters

Many statistical and mechanistic model approaches predict an increase in damage probability with increasing tree height although the impact varies with species. In many mechanistic models stem taper (height/diameter ratio or h/d ratio) is also identified as being important in controlling storm damage vulnerability (see Chapter 2.2). Other factors such as stem volume, mean diameter, volume indices and stand age have also been found to be good predictors of the probability of damage in post storm damage empirical analyses. However, height (in particular dominant height) has an advantage over other factors as a measure of vulnerability because it is relatively independent of silvicultural treatment and, even though height is generally more difficult to measure than stem diameter, recent advances in airborne LiDAR[1] allow measurement of the height of every tree in a forest at a relatively low cost.

1 LiDAR: Light Detection and Ranging: Remote sensing method allowing detailed examination of the surface of the Earth

Stem taper (h/d-ratio)

The effect of an increasing damage probability with decreasing taper or increasing height/diameter at breast height ratio is described in many investigations The impact of taper on the probability of stem breakage or uprooting is usually not possible to include within statistical models due to a lack of a reliable and comprehensive enough database. However, the effects of taper on stem breakage and uprooting probabilities can be evaluated using mechanistic models. It should be noted in this context that stem taper is influenced by thinning and thus often used as an indicator for stand stability and individual tree stability prior to a thinning (used to select the most vulnerable trees for removal).

Another source of evolution of taper over time is a tree's natural growth pattern with fast height growth in the early stage and decreased height growth with maturity. Thus, older trees naturally have lower h/d ratios. It is important to consider tree or dominant stand height as an indicator of wind loading first and then, in a second step, to analyse the impact of taper on stability. Considering only the effect of taper on storm risk without considering the effect of height may lead to false conclusions on the stability of stands.

Lower h/d ratios, which have been found to indicate lower risk of snow breakage and therefore indicate better individual stem stability are not necessarily a sign for higher stability in general. Lower h/d ratios coincide with larger crowns and thus increase the windload or drag of trees. Therefore, the h/d ratio may affect storm risk in opposing directions. The evidence from different studies is that h/d ratio is not always a good indicator of stand storm resistance although it is probably a good indicator of individual tree relative stability within a stand.

Management operations

Silvicultural interventions can influence storm risk in many ways. In the long term, the choice of tree species (see above) and rotation age or target diameter determine the principal risk predisposition of forest stands. Second, the effect of rotation age or target diameter on storm risk is the result of the associated increase in tree or stand heights, which are also correlated to age. In addition, thinning also influences storm risk. When performed at an early stand age, thinning has the effect of increasing the stability of individual trees. This has been ascribed to increased growing space for individual trees promoted through thinning that improves development of structural roots and stems. In taller stands, however, thinning tends to temporarily destabilize stands, mostly by disrupting the canopy and increasing its aerodynamic roughness. Since the canopy recloses again usually between 2 and 8 years after a thinning, this temporary destabilization affects the risk of damage to stands in the short term. While thinning has been recognized as a risk factor, it remains uncertain how important the effect of this silvicultural intervention is when compared to other known factors influencing storm risk such as tree species, tree height, height to diameter ratio and site conditions. There is evidence that late moderate to heavy thinning can increase vulnerability, while pre-commercial and light thinning at regular intervals can improve storm resistance.

Timber removals are often found to destabilize stands if they remove dominant trees. This observation is plausible since dominant trees usually have a better developed structural rooting system than co-dominant, intermediate or suppressed trees and may therefore form a stable "skeleton" or "scaffolding" for the stand. Removing these firmly rooted trees leaves the less stable individuals in the stand. In addition, these less stable trees are also then exposed to higher wind loads, since removing the taller dominant trees increases the wind speed in the canopy of the sub-dominant trees, because the sheltering effect of the dominants is removed.

There is evidence of augmented storm risk with increasing volumes of removed timber probably due to a temporary disruption of the canopy surface, which increases turbulence and tree swaying. Other studies also quantified that thinnings in general have a damage increasing effect, but could not state whether this impact was directly related to the amounts of timber removed. However, all these findings indicate that thinning operations temporarily reduce the collective stability. Seed-tree cutting (felling) and special cutting (tree felling for ditches, roads or power lines, or sanitation cutting after damage) may also increase the probability to storm damage because of the gaps they open in the canopy (see Chapter 2.2).

Important Stand and Management Factors

Tree height is the single most important factor indicating stand stability with trees increasing in vulnerability (lowered critical wind speed) with height.

Height to diameter ratio is not always a reliable indicator of stand stability but can be a good indicator of the relative stability of individual trees within a stand.

Heavy thinnings, especially late in a rotation, will increase the risk of wind damage

Soil characteristics

Soil properties are known to affect the level of impact of storm damage. This is true for spruce, particularly for those rooting in soils where oxygen availability is severely restricted by temporary waterlogging (see Figure 28). It has been suggested that the occurrence of waterlogged soils is one possible factor responsible for the increase of storm damage in Europe. Soil water balance is thus used as a significant predictor in storm damage modelling. Very wet (peaty) humus forms were found to have equally significant effects on storm damage as waterlogged soils.

It was also found that storm damage increased with a growing deterioration of the humus form, which usually leads to higher soil acidity. Although the mechanisms behind the relation between storm damage and soil acidity are not completely understood, soil acidity is considered a significant risk factor for storm damage.

Terrain characteristics

Investigations of damage caused by the 1999 storm Lothar in the Northern Black Forest showed the highest levels of damage in passes between mountains, west to east running valleys and westerly parts of the first mountain range. This matched a statistical analysis of the same storm which showed a higher frequency of damage on westerly exposed sites.

Other studies have given contrasting importance to wind speed and topographic shelter variation in explaining storm damage locations, with some studies finding highest damage where the wind was least gusty and the shelter highest. This may be as the result of tree acclimation, with trees growing in the most exposed locations being more stable than trees which are normally well sheltered from the wind and which can be badly exposed under very strong storm conditions.

Important Site and Terrain Factors

Anything that reduces rooting depth can increase the risk of wind damage

Waterlogging of soils increases the vulnerability of stands

Trees on acidic soils appear to have an increased vulnerability to wind damage

Passes between mountains are found to have increased damage

Valleys running from west to east have higher damage levels in storms (for storms with strong westerly winds)

The first westerly slopes on mountain ranges are susceptible to increased levels of damage (for storms with strong westerly winds)

Stand structure

Stand structure is probably one of the most difficult parameters to assess and include in storm risk predictions. Wind tunnel and airflow modelling studies have shown that the structure of the stand affects the shape of the wind profile with implications for the wind loading of individual trees under different forest configurations.

Empirical modelling studies suggest that on sites of moderate exposure, an irregular stand of spruce is more wind stable than a conventionally thinned regular stand, although the advantage disappears with increasing exposure. Hence, irregular stands may provide structures with more stable characteristics, but these cannot be considered in isolation from the prevailing wind climate and the local site type.

As the current versions of mechanistic models predict the risk for the mean tree within a stand or at its newly created edge, it should be noted that this approach only works well for regular, single species stands. In heterogeneous stands different trees will not necessarily have equal risk. Furthermore, these models do not capture the process of wind damage in real stands. In reality, the failure of one tree alters the wind regime for its neighbours and may make it more liable to damage and recent model developments now incorporate this process.

Wind risk models

Models support the calculation of the wind risk in forests. Empirical models are based on statistical evaluation of damage in stands after a storm whereas mechanistic models use engineering principles to calculate the risk. Empirical models are more accurate for forests in the area where they were developed (e.g. the empirical model "Lothar" is applicable in Central Europe). Mechanistic models are more adaptable to different forest conditions and allow incorporation of the impacts of a changing climate. They are available (e.g. "ForestGALES", "Hwind", "FOREOLE") for the major conifer species growing in Europe but not currently for broadleaf species.

Surrounding forest

Several studies strongly advocate a significant influence of edge structure and upwind forest gaps on damage probability. Upwind gap size, distance from upwind stand edge and the length of the forest edge have been shown to be important factors in predicting levels of damage (see also Chapters 2.1 and 2.2). The structure of the forest edge might also be important but this is often difficult to assess or such information is rarely available (see discussion in Chapter 2.1). For more than one century the optimization of the so-called "spatial order" (the spatial position of different forest stands to each other according to their age and height) in order to minimize storm damage was a crucial goal of forest management planning in parts of Central Europe. From recent storm damage the success of aiming to always locate the oldest stands in downwind positions by means of long-term "intelligent" cutting regimes appears to be very limited.

Importance of different variables

Overall forest stand characteristics were found by statistical analysis after several storm events to be more important for predicting long-term storm damage than soil, site, topography or wind speeds during a storm. Tree species and average tree or stand dimensions, especially height, have been found to be the most important factors controlling storm damage in the forests typical of central Europe with small-scale harvesting interventions (typically single tree selection) or managed with "close-to-nature" systems and with long rotation periods.

In contrast, in short-rotation clear-cut systems more typical of northern Europe there is less variation in tree height within stands and these systems are also usually monocultures with clear-fell replanting regimes. In these circumstances variations in individual tree shape as indicated by taper are likely to be more important and the impact of upwind clear fell areas has been found to be extremely important.

Potential management activities to reduce storm damage

These are discussed in detail in Chapter 4.2 but some general rules that can be determined from observations of actual wind damage in forests are summarized in the highlight box below.

Important Factors Affecting Risk of Wind Damage

General Observations

- Conifers appear to be generally more vulnerable than hardwood species.
- Spruce and poplar are among the most vulnerable species
- Silver fir, European pine, oak and beech are amongst the least vulnerable
- Waterlogged soils or soils with restricted rooting increase the vulnerability of trees
- Trees on acidic soils are more at risk

In long rotation systems (high final tree height and high target diameters)

- Early thinning to reach target diameters quickly and at lower heights reduces wind damage risk
- Slopes and valleys exposed to the prevailing wind are particularly susceptible to wind damage
- Thinning in the late stages of a rotation increase the risk of wind damage

In short rotation systems using clearfell/replanting

- New edges on the upwind side of stands can produce a large increase in wind damage risk
- Trees with higher taper appear to be the most wind firm within a stand
- Thinning on exposed sites can lead to increased wind damage

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3.

Impacts of Storms

3.1. Influence of storm damage on the forest carbon balance

Esther Thürig, Frank Hagedorn and Anders Lindroth

Forests store large quantities of carbon (C) in living biomass, dead organic matter and soil. This was one of the main reasons to include forests and forest management in the Kyoto Protocol (UNFCCC 1997). Forests can act as a C source or sink, depending on the balance between uptake of C through photosynthesis and release of C through respiration, decomposition, or large scale disturbances such as harvesting activities, fire, or wind damage. Globally, forests still accumulate C and therefore act as a global C sink. Frequent disturbances by wind damage may alter this overall C sequestration capacity of forests. If forest ecosystems are to be accounted for in mitigating atmospheric carbon dioxide (CO_2), it is crucial to understand and quantify the impacts of disturbance on net ecosystem exchange (NEE, i.e., the change in C pool and fluxes with time). In this chapter, we give an overview of the effect of wind damage on the different C pools and fluxes in forests.

Importance of forest C budget

Global estimates of C stored in forest vegetation, dead wood, litter, and soils range from 861 ±66 giga tonnes of C (Gt C) to about 1146 Gt C. Temperate forests store about 119 ±6.3 Gt C, thereof 48% in soils, 13% in dead wood and litter, and 39% in biomass. Boreal forests store about 272 Gt C.

Using forest inventory data and long-term ecosystem C studies it is estimated that there was a global forest sink of 2.4 ±0.4 Gt C per year for 1990 to 2007. Temperate and boreal forests were estimated to account for a C sink of 0.72 ±0.08 and 0.5 ±0.08 Gt C per year, respectively and it has been estimated that the C sink of the European forest sector is around 0.14 Gt C per year.

Many countries decided to account for C changes in forests under the Kyoto Protocol. Changes in C stored in living biomass, dead wood, litter, and soil have to be reported according to guidelines given by the IPCC (Intergovernmental Panel on Climate Change). Many countries apply the so called *stock-change method* based on the difference in the amount of C between two stock measurements with a certain time difference. As data are often only available for past years, extrapolation of past stock changes is a common proxy for reporting of the most recent years. Large scale disturbances such as caused by wind damage can cause non-linear trends and make such extrapolations very challenging. Moreover, decomposition of wind damaged wood strongly depends on climate and management decisions. This makes the estimation of C budgets in all those pools even more difficult.

Globally forests are important carbon sinks. Frequent disturbance such as by wind may reduce the overall carbon sequestration of forests.

Effect of wind damage on C budget of forests

Frequent disturbances decrease the overall C sequestration potential of forests and should therefore be taken into account in medium- to long-term scenarios of the mitigation potential of forests. In Western Europe, wind damage by storms is probably among the most important natural disturbances. Wind damage to forests affects the C budget in two primary ways:

(1) Wind damage can reduce the living biomass and thus cause a reduction in C sequestration capacity.

(2) Wind damage enhances heterotrophic respiration above the level of a normally harvested forest and thus strongly increases decomposition of coarse woody debris (CWD), litter and soil organic C (SOC).

Both causes reduce net uptake from the atmosphere and therefore decrease the C sequestration potential. The magnitude of the effect on NEE depends on the loss of living biomass, on C pools and fluxes from deadwood and on the degree of soil disturbance.

Loss of living biomass

Wind damage reduces the amount of C stored in living biomass. The number of damaged trees can vary between complete stand destruction to only individual trees or groups of trees (see Chapter 1). In one study the stock change method recommended by the IPCC was applied to estimate the effect of wind damage on the carbon budget of old-growth coniferous forests. Data was used from a 1 ha plot in a coniferous forest on Changbai Mountain that was measured in 1981 and re-measured in 2010 after severe damage by a storm. A loss in living biomass from 148 to 124.5 t C per ha (-16%) was measured. The reduction of living biomass also causes a reduction or even complete elimination of photosynthesis and therefore a reduction in C sequestration. Analysis of the effect of tropical cyclones on sequestration rates of Japanese forests estimated a decrease in the canopy C gain by nearly 0.2 t C per ha and year for the 10–20% defoliation that occurred in 2004.

Trees that become wind damaged are typically in the upper range of tree height and age. A study in Sweden after the storm Gudrun in 2005 showed that the largest share of damage occurred in the oldest age classes of stands. Based on this data it was estimated that the normal rotation length was shortened by 0–30 years by the storm and this is probably a general phenomenon following wind storms. Since stands of this age class are normally large sinks of CO_2, the shortening of the rotation length must also be allowed for in carbon accounting.

C pools and fluxes from deadwood

Wind damage to trees transfers C stored in living biomass to C in dead wood. Compared to forest fires, CO_2 emission to the atmosphere do not occur directly after the disturbance but by decomposition of dead wood and litter over a certain time span. The increase of dead wood after wind damage can make a major contribution to the forest C balance. A half-life time of about 17 years for dead wood after wind damage suggests storage of C over several decades, and indicates a very different long-term C budget for naturally disturbed versus commercially managed forests.

In the above mentioned study, where the *stock change method* of the IPCC was applied, the disturbed stands were estimated to be a C sink of 29 t C per ha (+10%) despite the considerable loss of living biomass. The increase in deadwood carbon from 26.7 t C per ha to 55.1 t C per ha (+106%) and in soil from 124 to 148 t C per ha (+19%) prevented this forest from becoming an instant source of C.

However, as deadwood is continuously subjected to decay by heterotrophic respiration it permanently emits CO_2 to the atmosphere. It therefore depends on the measurement method and the time frame of the observation whether the overall C budget of wind damaged sites is affected positively or negatively by dead organic matter. Several studies indicate that the decay of deadwood accounts for approximately one third of the total respiration.

Wind damage effects on soil C

Wind damage to trees affects soil C cycling by altering C inputs and soil conditions:

(1) Wind damage leads to a sudden large C input to the forest floor in the form of coarse woody debris followed by an abrupt decline in litter fall.

(2) Soils are physically disturbed by uprooting which creates a distinct pit and mound topography and mixes organic layer material with the mineral soil.

(3) Soil microclimate is altered by the loss of tree crowns. In general, soil temperatures increase after wind damage due to greater radiation at the soil surface, while soil moisture can either increase as a result of a reduced water uptake by trees or decrease through increased evaporation from the soil.

These micro-climatic effects are, however, short-lived due to the regrowth of vegetation at the forest floor.

In general, wind damage is assumed to induce C losses from soils, the magnitude, however, depends on the decomposability of soil organic matter and the intensity of the wind damage, in particular physical disturbance through uprooting. Given that wind damage is one of the most important disturbance agents of the terrestrial C cycle, there are surprisingly few quantitative assessments of soil C balances following wind damage. Two main methods measuring soil C balance after wind damage are applied:

(1) Short-term soil CO_2 flux measurements

(2) Long-term comparisons between soil C stocks of wind damaged areas and adjacent forests not affected by wind damage.

In case studies, short-term measurements of soil CO_2 effluxes show relatively small effects of storm damage. After wind damage, CO_2 emissions from soils have been observed either to increase slightly (+8 to 30%), to be negligibly affected, or even to decrease slightly (-27%) in different studies. However, in intact forests, recent photosynthates contribute 50 to 70% to soil CO_2 effluxes and since these fluxes are largely negligible in wind-damaged forests, comparable fluxes in wind damaged and control areas indicate C losses from soil organic matter because of wind damage.

Long-term comparisons between soil C stocks also show considerable soil C losses from forest floors after disturbance. C losses after disturbance by clear cutting of about -50 t C ha^{-1} have been reported, suggesting that wind damage may lead to enormous C losses. However, based on a re-sampling of soils and the modelling of soil C fluxes this strong decline in soil C storage has been questioned because harvesting and wind damage can lead to an apparent loss of C because they may mix organic layer material with the mineral soil. A very extensive soil survey C loss in both organic layers and B horizons (subsoils) 95 years after a wind damage event in Alaska showed an overall decrease in soil C stocks from 216 to 157 t C ha^{-1}.

In Switzerland the impact of the two storms, Vivian in 1990 and Lothar in 1999, on soil C storage were assessed by quantifying soil C stocks of wind damaged areas and adjacent forest in 2008, 18 and 9 years after the storms respectively. While Vivian primarily affected the Alpine areas, Lothar affected the Swiss Plateau. Comparisons of soil organic carbon (SOC) stocks from 14 Lothar and 5 Vivian sites with undisturbed sites showed a contrasting response to the two storms in the two regions (Figure 15). Nine years after Lothar, soil C stocks of the wind damaged areas were only slightly smaller in the mull-type organic layer and uppermost 10 cm of the mineral soil (-4 t C ha^{-1}). By contrast, 18 years after Vivian, the thick mor-type organic layer of the Alpine soils was almost entirely lost. On average, wind damage affected soils stored 25 t C ha^{-1} less than the control soils. The different responses are primarily due to the greater storage of easily decomposable C in the thick organic layers at the alpine site and soil organic matter (SOM) stabilization in the mineral soils of the Swiss Plateau. Moreover, the re-establishment of new vegetation was much slower in the Swiss Alps than in the Swiss Plateau, where the new vegetation contributed faster to a new litter layer with a smaller C/N ratio than in the undamaged forest.

In summary, soil CO_2 efflux measurements and comparisons of C stocks indicate C losses from soil organic matter after wind damage. Little attempt has been made to assess soil C stock changes quantitatively. The magnitude and duration of soil C losses depends on SOM decomposability, vegetation regrowth, and the intensity of wind damage.

How much carbon is lost to the atmosphere after storm damage is a function of a number of factors including the amount of organic material in the soil, how quickly vegetation re-establishes on the site, and the amount of tree residues left on site.

Full C accounting after wind damage

After a wind damage event, the affected area is mostly a complex array of fallen trees, uprooted and broken root systems, and debris of various sorts, which means that it is very difficult to directly quantify by in situ measurements the net CO_2 exchange between the surface and the atmosphere. Chambers can be used to measure soil effluxes and also respiration from wood material but the up scaling is an almost overwhelming task. Also

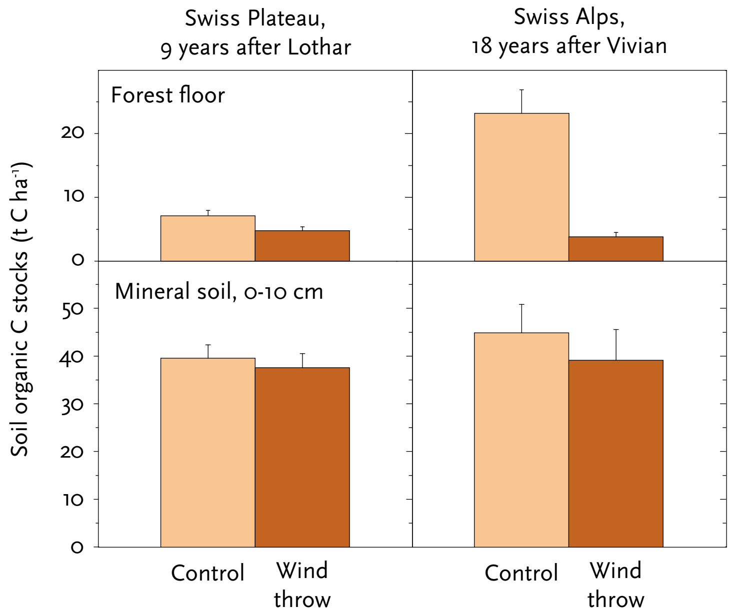

Figure 15. Effects of wind damage on soil organic C stocks in the forest floor and mineral soil at 0 to 10 cm depth. Means and standard errors of 14 sites in the Swiss Plateau and 5 sites in the Alps. Soil was sampled at 8 locations in wind damage areas without uprooting and in adjacent forests (after Rusch et al. 2009).

after the area has been cleared there is a lot of residues remaining, stumps, disturbed and undisturbed soil patches and vehicle damaged areas. This makes it difficult task to quantify the losses of CO_2 to the atmosphere. In practice it is only micrometeorological methods that can be used to integrate the fluxes over larger areas, typically hundreds of square meters, and thus measure large scale Net Ecosystem Exchange (NEE). In order to assess the total effect of CO_2 exchange caused by wind damage, the relationship between NEE and stand age must be known both for the undisturbed forest and for the forest affected by wind damage.

Based on a chronosequence study in four different European forests and on two wind damaged areas in southern Sweden a simple model describing NEE as a function of maximum NEE (NEE_{max}) and relative rotation length (R_{rel}) for the first rotation after a wind damage has been developed:

$$NEE = NEE_{max} \cdot (f - f_s) \quad (1)$$

where f is the fraction of NEE_{max} (largest annual uptake, a negative value) during the normal rotation period and f_s is the additional fraction of NEE_{max} caused by the wind damage:

$$f = -1.12 + 1.59 \cdot R_{rel} - 3.75 \cdot R_{rel} \cdot \ln R_{rel} \quad (2)$$

and

$$f_s = NEE_0 \cdot e^{(-R_{rel}/\tau)} \quad (3)$$

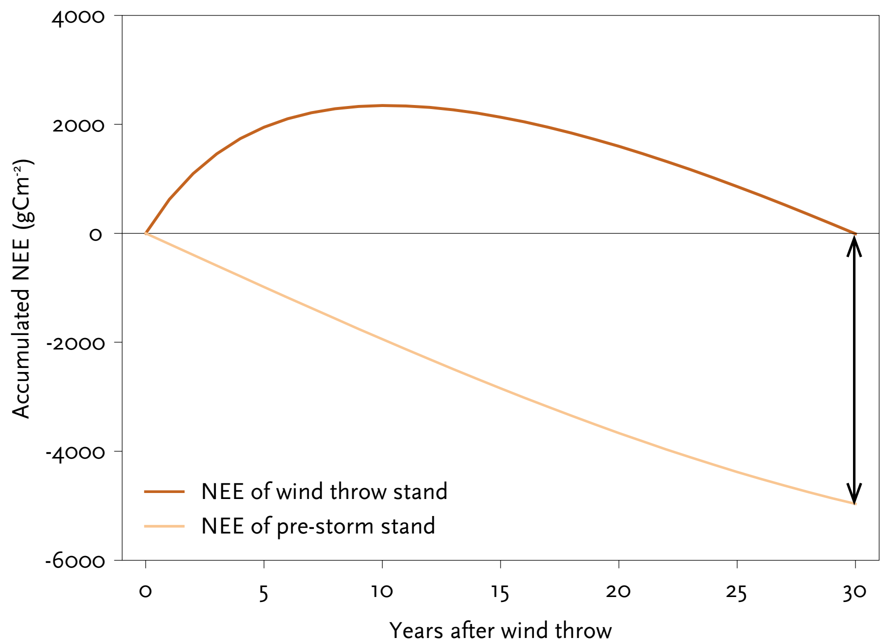

Figure 16. Accumulated NEE the first 30 years after wind damage in comparison with the NEE of an undamaged stand. The arrow indicates the total loss of uptake after a time period of 30 years.

Where NEE_0 is the relative increase of NEE as compared to the normal during the first year after wind damage and τ is the time constant of the process for the conditions to return to normal.

With a time constant of 0.05 (relative age), a relative enhancement of $NEE_0 = 3$ a NEE_{max} of -2 t C $ha^{-1}yr^{1}$ (equal to -0.2 kg C m^{-2} yr^{-1}, typical for average Swedish conditions) and a rotation length of 70 years, the accumulated NEE of the wind damage event would be close to zero after 30 years (darker line in Figure 16). This should be compared to the net uptake that would have occurred if the wind damage had never happened (lighter line in Figure 16). In total over the 30 year period, the difference between prior and post wind damage conditions would be a lost net uptake of 50 t C per hectare. The maximum difference between prior and post wind damage stands occurred after 22 years with a difference of 53 t C ha^{-1}. It is important to point out that this example concerns only the effects of wind damage on the direct exchange of CO_2 between a stand and the atmosphere. Indirect effects caused by the wood material that has been removed from the wind damaged areas and used as construction material, pulp etc., must also be considered in order to assess the total effect on the atmosphere. Such analyses are beyond the scope of this chapter.

The major uncertainty in this model is the time constant (τ); there are no published long term studies on wind damaged areas that can be used to shed light on how reasonable the chosen time constant of 0.05 is. Another uncertainty is in NEE_0, which here is based only on data from two sites in Sweden.

Management options to mitigate C offset of wind damage

The best option to avoid emissions or reduced uptake is to avoid wind damage from the very beginning. Management options to reduce wind damage are discussed in Chapter 4.2.

After wind damage has occurred, re-establishment of a new forest as fast as possible is the most important measure in order to reduce the negative impact of the damage. Depending on the local conditions, ground vegetation can develop rapidly after a wind damage event, particularly since a lot of nutrients are released. Care should be taken to keep this vegetation intact as much as possible during planting since it contributes to a considerable uptake of CO_2 from the atmosphere. Thus, selection of tree species that are competitive in relation to ground vegetation is important and ground clearance to plant within this vegetation should be minimized.

Wood from wind damaged areas cannot normally be used for high-quality wood products and products produced from such wood after wind damage often have a half-life that is less than 17 years. Therefore, despite being a source of C in the forest, not harvesting of deadwood after wind damage could generate a temporary C-storage in the forest with additional possible positive effects on nutrition and biodiversity. However, consideration needs to be taken of the potential for any subsequent insect outbreak if large quantities of deadwood are left on site.

Another option to mitigate the effects of the wind damage would be to utilize as much as possible of the residues that are left on the ground after the logs have been taken out from the area. Removal of wind-damaged timber decreases instantaneous CO_2-fluxes from the soil surface and forest floor, whereas the highest instantaneous fluxes are found in areas with total canopy destruction and where wind damaged material has been left on site. Using the residues for energy and thus substitution of fossil fuels will also contribute to reducing the net effect on the atmospheric concentrations of CO_2.

We conclude that storm effects must be accounted for in regional C budget estimations and that it is obvious that the risk of increasing storm damage to forests, in a changing climate (see Chapter 5.1), must be considered in the assessment of the future forest C balance.

Conclusions: Wind damage has an important impact on the carbon balance of forests. This is because storm damage increases carbon losses from the soil and overall carbon sequestration in trees is reduced. In addition the damaged timber that is removed is often used for short-lived products, which reduces the overall storage of carbon. Therefore, storm effects need to be taken into account in regional carbon budget estimates.

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3.2.

The economic impact of storms

Marc Hanewinkel and Jean Luc Peyron

The evaluation of the global economic impact of a storm is a difficult task because multiple factors are at stake including the magnitude of the event, the complexity of the consequences of the damage, the context in which the event occurs, the influence of measures undertaken (to mitigate the damage), and possible short term beneficiaries (e.g. logging contractors, nurseries). In this chapter we address these different points in order to propose a storm economic severity scale and finish by providing some simple examples.

We can distinguish at least three very different degrees of damage depending on whether the damage is spread out, severe but localized, or both severe and wide spread at the industrial supply scale (often referred to as catastrophic damage).

The original magnitude of the storm is measured in intensity (wind speed), duration, and extent of damage (area affected). Some weak storms cause low level and spread out damage similar to a thinning, which cause some losses but are not a big problem, even for affected owners. In other cases, storms can be quite intense but the impact localized so that damage is heavy but limited in area. They can have severe consequences for owners but do not have noticeable effect for the whole sector. The disastrous character of a storm really shows when they are both intense and large in area, so that the volume of wind damage exceeds the annual average harvest of an area supplying main forest industries. In this latter case, economic conditions are disrupted not only for the storm affected forests but also for the industries and services depending on them and consequently also forests not directly affected by the storm.

When a catastrophic storm occurs the forest is directly affected through overturned or broken trees. Associated activities such as the forest industry, recreation, and transport services can also be affected at the same time, for example due to damage to buildings, roads, railways, power-lines and telecommunication services. The subsequent sensitivity of the forest to further risks, the potential for revenue, and the clearing up and forest restoration, all depend on the speed of wind damage removal. Forests initially spared from damage must postpone cutting to avoid negatively affecting wood prices at the time of the crisis. Finally, the resulting imbalances, concerning both forest ecosystems (e.g. explosion of insect populations, game damage, overall forest health) and economics (e.g. market saturation, company closures) are likely to increase the deterioration of the biological and economic conditions.

Beyond the initial phenomenon, storm impact depends on the response of the whole chain and must be endured but can, by a number of means, be minimized in their effects. The economic evaluation therefore needs to take into consideration all different factors, all affected sectors and their interdependencies, including exceptional measures undertaken and their immediate or longer-term consequences. It is a difficult task, especially due to the need to anticipate the subsequent effects of a storm event and the implemented measures. Even when the evaluation is done *a posteriori*, an important element of uncertainty remains.

A storm leads to a sequence of impacts within the forest/wood sector, which can be qualitatively described, but for which a quantitative evaluation of the economic impact is often hard to make.

The forest loss is made up not only of the cost of restoring access and the reduction in value of the timber, but also in the reduction of the future value of damaged or undamaged stands (including destabilised stands) and of additional renovation costs.

For a forest owner a storm causes several losses resulting from either the costs additional to those of normal management or the reduced income. Once emergency operations to restore access to the forest are complete, the main loss often comes from the reduced market value of the timber whose mechanical properties are compromised even if the timber is unbroken. Further also from the lack of landing sites for stacking harvested timber, and the price drop resulting from the large available volumes, or from the organization of expensive measures to either store timber long-term or export outside the affected area (long-distance transport).

In addition storms affect stands on the periphery of the major areas of damage often as isolated gaps or damage to individual trees. These stands may have to be prematurely felled because of their increased vulnerability, resulting in a loss of revenue because they have not normally reached their economically optimum rotation age. Trees still standing within a storm devastated area as well as in unaffected adjacent stands also suffer an expectation value loss because of the storm. Within and on the edge of the damage some trees are weakened towards future biotic (diseases, insects, etc.) or abiotic (wind, drought, fire, etc.) threats. Their management is also altered by the storm with planned cuttings postponed and plans modified to integrate the disruption in the forest. Although this opportunity cost is lower than the loss associated with the fallen trees, it affects large areas and can thus be considerable.

After harvesting of fallen or broken trees, stand restoration needs specific techniques which differ from normal practice. Ground cleaning is needed to both make silviculture operations easier and limit fire or pest risks, immediate planting is often imperative after a storm, and species other than those normally planted may sometimes need to be used due to plant availability. This therefore generates additional restoration costs to be added to both the access restoration costs, loss of markets and the reduced expectation values mentioned above.

Damage resulting from a storm will create an increase in business activity. It can vary according to the type of company/sector involved and in the way that the forest area has been affected.

Storms also have consequences on non-market activities, which are even more difficult to evaluate.

Generally speaking, a storm requires additional forest management in the short-term within the affected areas (logging, cleaning, restoration, etc.) and a decrease in the unaffected areas (felling postponement). This activity is sustained over the mid-term in the affected areas (stand tending and improvement) while the delayed activity in the unaffected areas will progressively catch up.

Insurance agents are extremely busy after major storms but insurance for storm damage is normally incomplete and is often compensated for by subsequent public financial support. Catastrophic storms often lead to difficulties for the reinsurance system due to the extent of losses in storm affected areas. For the European Union, European state and local governments the costs of dealing with storm damage obviously represent an additional burden on public finances.

However, a storm leads to strong local activity followed by a decline or even collapse of activity before returning to a more stable situation for endeavours such as logging, transport, and storage. Activity levels in the mid-term are reduced compared to the pre-storms situation if the available resources become reduced compared to the productive capacity of the forest. The phenomena can even have an impact outside an affected area whose production capacities are inadequate for the scale of impact. However some business sectors not involved in the management of the wind damage are likely to benefit. For example, the banking sector has increased demand to guarantee purchase of roundwood and to finance new investments such as timber storage.

The industries most affected by the storm damage are primary processors (e.g. sawing, slicing, peeling, production of panels and pulp). They are also likely to increase their short-term activity but they have to deal with a change to their supply in terms of the size and quality of delivered wood. Some companies depending on particular wood quality features may face severe shortages in supply of the required timber due to the effect of the storm and post-storm management. In the mid-term, such companies may need to deal with a reduction of locally available resources and therefore with an increase in their supply costs. However, consequences vary enormously depending on the normal level of production in an area prior to the storm. Impacts are limited in most European areas where the felling rate of available resources is well below 100%. In contrast, in the Aquitaine region of France, where the annual fellings in 1999 were close to the annual increment, the two successive catastrophic storms of 1999 and 2009 created a critical imbalance between the allowable cut and the existing industrial production capacity.

The nursery and reforestation sector is initially affected by a decrease in activity due to cancellation of orders which cannot take place until after logging and cleaning up after the storm. Afterwards, the sector is in strong demand for several years due to the replanting of damaged stands wherever natural regeneration is not possible.

The consequences of storm damage described above gradually affect the whole economy in a way which is difficult to fully comprehend. Generally speaking, under the exceptional circumstances following a storm most decisions are made with a lack of certainty and can be risky. This is true both for e.g. the banking business which may support exceptional activities in the forest and the wood harvester who is faced with a tangle of damaged trees to be cut. Finally, catastrophic storms may bring into question previous management choices or generate concerns about the future. This was the case in Germany, especially after the 1990 storms, and in the Aquitaine region following the 2009 storm.

After catastrophic damage, forest visits are obviously more dangerous and the landscape less attractive to visitors. Surveys have shown a higher sensitivity of the public to safety issues as compared to landscape effects but still will want to walk in the woods even if its appearance is degraded. The consequences of storm damage in for the forest carbon balance are discussed in Chapter 3.1.

The context within which storm damage occurs is important in determining how well the required actions following the storm can be addressed in operational terms.

Public policies and forest management measures are able to limit the crisis, in particular by making it easier to clear the wind damaged stands and to restore the forest.

A number of factors can affect the impact of a catastrophic storm. The presence of a contingency plan prior to a storm and a good organization of the forest sector make a significant improvement to both decision-making and the speed of response after the storm. In addition, a favourable economic situation makes absorption of excess roundwood into the market easier by maintaining a high demand both in quantity and price, and reduces the need for storage. From this perspective, favourable phenomena are strong economic growth, high oil prices which favours wood against its major competitors (other materials and energy supplies), and a weak currency which discourages imports and favours exports. The weather conditions following the storm can be very important for the subsequent health of undamaged stands. Further strong winds can lead to more tree damage, windy and dry conditions increase the risk of fire outbreaks, and warm conditions favour outbreaks of bark beetles.

Following the storm, a subsequent disaster must be avoided which would consist of not being able to make a good use of the fallen timber, in leaving overall forest activity disorganized, in increasing the chance of further secondary damage, in allowing the loss of high levels of carbon (see Chapter 3.1), in disrupting on a permanent basis recreational activities, and allowing a reduction of the water quality and soil protection functions of the forest. Political and strategic measures are therefore necessary in order to minimize these secondary impacts. They form an important part of public action that is a complement to the development of preventive measures focussed on future events. The political and strategic measures include emergency responses to restore access and minimize accidents, incentives for wind damage removal, storage, or long-distance transport, support of the revenue of foresters, prevention of additional impacts from other hazards, the strengthening of staff and budgets, aid for cleaning and restoration (see Chapter 4.3). The above measures may affect markets by modifying the supply and demand for both wood and restoration operations. Economic impacts, however, are hard to gauge and their real impact is seldom evaluated. They obviously contribute to reducing the impact of storms on stakeholders but at a cost to public finances.

Due to many additional costs, wood depreciation and financial risks following storms, one can hardly argue that some sectors and businesses will benefit from such a crisis.

Catastrophic storms may have their consequences worsened by a lack of means for exploiting the damaged timber or, in the mid-term, by a lack of available forest resources to support industry in the affected area or even by both.

The decrease in the market value of wood damaged or blown over by a storm suggests that buyers would largely benefit. We must however remember the many reasons for this decrease:

- the abandonment of roundwood in the forest that would be very expensive to extract as compared to its value;
- the deterioration of wood whose quality does not allow it to be used for standard processing;
- on average smaller log sizes are abundant as compared to those from normal harvesting;
- low stumpage value of the timber due to the higher than normal logging costs in wind damaged stands (the roadside price includes these high logging costs which are added to the reduced stumpage value with the two elements partially balancing);
- costs increase for further operations: storage, long-distance transport; the law of supply and demand forces the buyer to pay less for the timber in order to cover the additional costs discussed above together with the higher risk incurred in a market saturated with timber.

Although some may benefit directly from storm events, particularly if the response measures are poorly thought through and cause unwanted impacts, they mainly cause losses to forests owners, insurers, and public authorities.

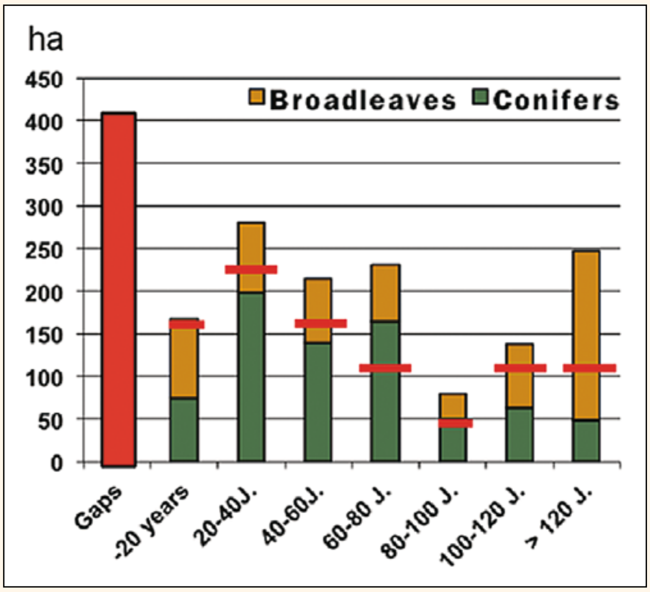
Damage from a catastrophic storm is usually concentrated but its impact can spread out beyond the area of direct damage and affect whole industrial supply basins. For example, it is possible that the adopted measures are limited because of financial constraints, and logging or transport capacity. Under such circumstances, roundwood whose removal would be profitable remains in the forest, thus increasing the loss of market value. In addition, in some cases it is possible that future resource availability is so reduced that the future supply to the wood-based industries is compromised.

The economic damage linked to the 1999 and 2009 catastrophic storms was assessed approximately in France. In 1999, storms Lothar and Martin blew down approximately 176 million m^3 of wood valued at 6 to 7 billion Euros. In 2009, storm Klaus accounted for approximately 43 million m^3 which represented an economic damage of approx. 2 billion Euros. As we can see, these amounts are quite high, even without considering other impacts. They explain why a great amount of attention should be given to storms, that preventive actions need to be put into place (see Chapter 4.2), and contingency plans drawn up in advance of major storms (see Chapters 4.1 and 4.3), rather than developing a response afterwards.

Box 2. Case study of a forest enterprise badly affected by storm Lothar in December 1999.

Let us consider a German community that was hit on the 26th of December 1999 by storm Lothar with wind speeds of up to 200 km/h. This community of 12,500 inhabitants is situated in the foothills between the Black Forest and the upper Rhine valley. Its forest property encompasses some 1,400 ha, mainly on fertile soils, producing roundwood, having protection and recreation functions also, and being very important for the life and the income of the community. Before the storm, the stands were site-adapted and were a mixture of beech, spruce and silver fir.

Lothar destroyed almost 50% of the forest area, and large parts of stands older than 60 years blew down in a few minutes. 245,000 m^3 of timber, representing around 25 times the annual allowable cut of the forest unit were damaged, and reduced the forest value to 30% of what it was before the storm. In addition major traffic roads and overhead power lines were also disrupted. The size of the damaged gaps varied from small spots of less than 0.1 ha to large areas of more than 40 ha. The quality of the timber affected by the storm differed: high quality timber (mainly beech of large dimension) was still suitable for veneer production; construction timber of normal quality (conifers) was highly damaged after storm damage and partly only usable for bio-energy.



Age class distribution of the community forest before (columns) and after (red lines, column "gaps") the Lothar storm.

Box 3. Influence on timber prices of the storm Lothar and its biotic consequences.

The effect on of timber prices of storms can be illustrated with the German statistics for Norway spruce sawlogs in German State forests. The influence of the storm in 1999 is clearly visible with a decrease of the price of around 25%. Yet, even this decrease was less dramatic than in the years after the storm Vivian/Wiebke (February 1990) that was not concentrated only in Southwest Germany like Lothar. After a small increase up to 2003, the prices decreased again in 2003 and the consecutive outbreaks of bark beetles that affected the prices until almost 2006. The influence of storms on bark beetle infestations has been demonstrated and modelled based on a long-term time series. For southwest Germany it was estimated that up to 25% of the damage after Lothar, was caused by bark beetle outbreaks in the follow-up of the storm, which is not unusual for such large disturbances.

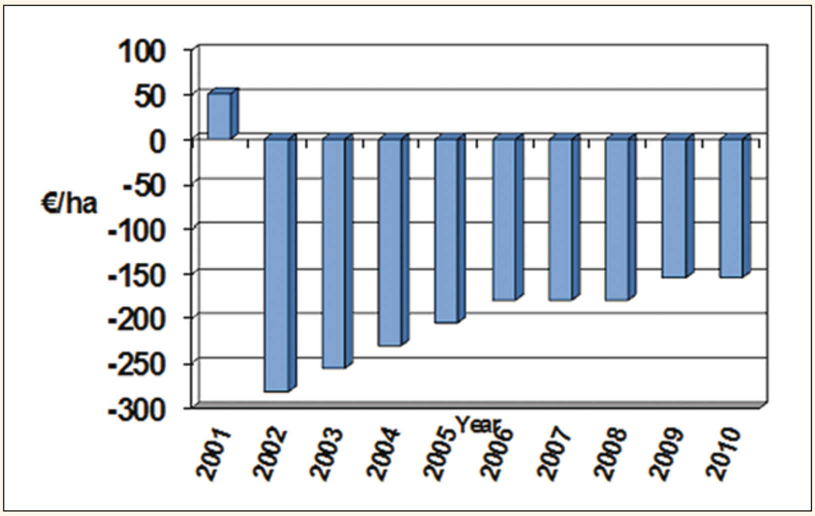
Development of the timber prices for Spruce sawlogs (B-Quality) at roadside from1995 to 2008 in the State Forests in Germany. Index: 2010=100%. Data source: Statistisches Bundesamt 2012.

Box 4. Change in the costs and revenue structure following a storm.

For the forest enterprise described in Box 2, the change in economic conditions following the storm was assessed. A simulation was conducted to project the development of the community forest for the decade after the storm (2001–2010) taking into account the new age-class structure and using a single-tree growth simulator Silva 2.0.

The results show an initial positive operational result following the storm with the sales of storm damaged timber. However, 2 years afterwards, large amounts of money had to be spent for replanting the open areas created by the storm and for tending of the subsequent young forest stands. Given the other costs and especially the cost of administration (mainly due the long-term contracts of the work force), the forest enterprise produces a yearly deficit in the range of 150 to 300€ per ha until 2010.

The deficit only slowly decreases as the possibility of generating additional revenue from the few remaining older stands is limited and the cost for young growth tending and pre-commercial thinning persists for a long time. For the community forest, the break-even point is expected to be only reached by 2025, despite efforts to rationalize, and to reduce the workforce.



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3.3.

Impact on industry and markets – roundwood prices and procurement risks

Peter Schwarzbauer and Peter Rauch

We will focus on two important aspects of how storms affect roundwood markets. The first is the effect on roundwood prices; the second is the effect on roundwood procurement, because high amounts of salvage wood may decrease the potential availability for future harvests.

Before investigating these effects, by using Austria as a case example we will schematically illustrate the impact of storm damages in the setting of a perfectly competitive polypoly market (large number of small buyers and small sellers, none of which can influence prices) for a homogenous roundwood product (Figure 17).

A storm would cause a sudden shift of the roundwood supply curve (S) to the right (S^S). Forest owners are forced to supply more roundwood at the same price (P*). The

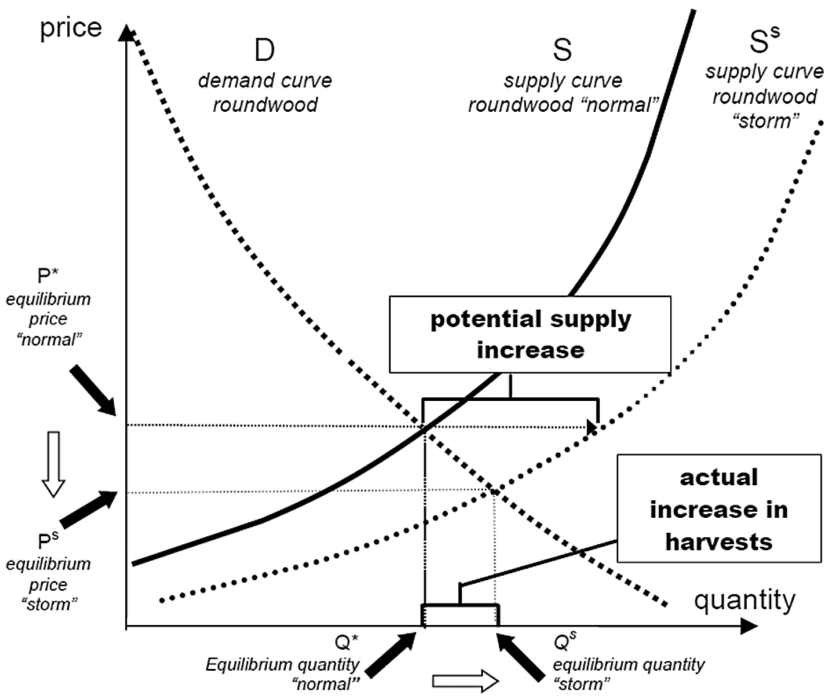

Figure 17. The impact of salvage wood harvests on the market equilibrium (schematic diagram).

demand curve (D) and the supply curve (S^S) form a new market equilibrium at their intersection with P^S and Q^S as equilibrium price and quantity. Because demand has not changed the actual increase in quantity is less than the potential increase caused by the storm. Forests owners react by decreasing their scheduled harvests in order to compensate the supply shock. But the actual quantity supplied (Q^S) has increased and the roundwood price (P^S) has decreased compared to the original market equilibrium (Q^*, P^*).

The magnitude of actual quantity and price changes due to a storm event on a national level in the short run depend on the following factors:

- amount of timber felled by the storm (intensity of the event)
- possibilities to increase roundwood exports and decrease roundwood imports
- possibilities and capacities to store roundwood: i.e. taking quantities out of the market for a while
- degree of capacity utilization[1] in the forest-based industries at the time of the storm event: the lower the degree the easier it is to increase production and compensate the supply shock.
- price elasticity of demand: the more price-elastic the roundwood demand the less prices will fall and the less the actual supply will differ from potential supply.
- the decrease of average roundwood prices will depend on how much the quality of the salvage harvests will suffer from the storm event.

In addition, the change in harvesting costs due to a storm event may also have an impact on roundwood stumpage prices. Usually it is assumed that harvest costs after a catastrophic storm event increase due to the chaotic situation in the affected region and will push stumpage prices even further down than roadside prices. However, due to the necessity to harvest the storm felled timber as quickly as possible to avoid further damage (e.g. by proliferation of forest insect pests), harvest technology may change and justify larger equipment, larger amounts of harvested timber and even the construction of specific access infrastructure (e.g. forest roads) otherwise impossible when smaller scale harvests or selective cuttings are practiced. This could even decrease the costs of salvage wood harvests compared to "normal" harvests, which is particularly true in regions with mountainous topography (e.g. Austria).

Sawnwood prices are the main determinant for sawlog prices – storm events can interrupt that relationship.

In contrast to consumer goods the demand for roundwood is "derived" from the production of forest products or bioenergy, the demand of which is either directly triggered by consumers or by further processing. Therefore, there is also a correlation of prices between roundwood assortments and products produced with them which has to be taken into account when analysing roundwood price changes after storm events.

The focus here is on coniferous sawlogs because this assortment makes up about 60% of Austrian harvests and the price of pulpwood is less affected by storm damage.

1 What percentage of processing and roundwood storage capacity is being utilized at the time of the storm.

Figure 18 shows how close the index of the coniferous sawlog price (in this case spruce/fir 3a B roadside price) follows the index of the coniferous sawnwood export price. Statistical tests reveal that indeed the sawnwood price is the main determinant for the sawlog price with an elasticity of close to +1 (if the sawnwood price increases/decreases by 1%, the sawlog price also increases/decreases by 1%). The amount of salvage harvest has a comparatively low, but increasingly negative impact on the sawlog price over time. Although the average impact of salvage wood harvests on the sawlog price seems to be only moderate, it has to be kept in mind, that in years with exceptionally high amounts of timber felled by storms the impact on roundwood prices can be dramatic (see year 1990 in Figure 18); e.g. a drop of the sawlog price by 20% within two months occurred in the Austrian case.

The price developments as shown in Figure 18 suggest that the strong wind damage in 1990, which led to a considerable drop of the sawlog price in that particular year, also had a longer-term effect. After 1990 the general level of the sawlog price index seems to have been pushed down and since then has never again reached the level of the sawnwood price index. To test the hypothesis of a long-term down-shift of the sawlog price compared to the sawnwood price a pairwise t-test was applied for two periods: before the storm damage in 1990 (1965–1989) and thereafter (1990–2009).

In the period 1965–1989, the means of the two price indexes do not significantly differ from zero, while the difference of the two means in the period 1990–2009 significantly differ by more than 10%. The storm event in 1990 has significantly pushed down the coniferous sawlog price in the long run (as compared to the sawnwood price).

Close to 40% of total Austrian harvests in the last decade were salvage wood harvests. Because of this high general level, "normal" annual changes to salvage wood harvests

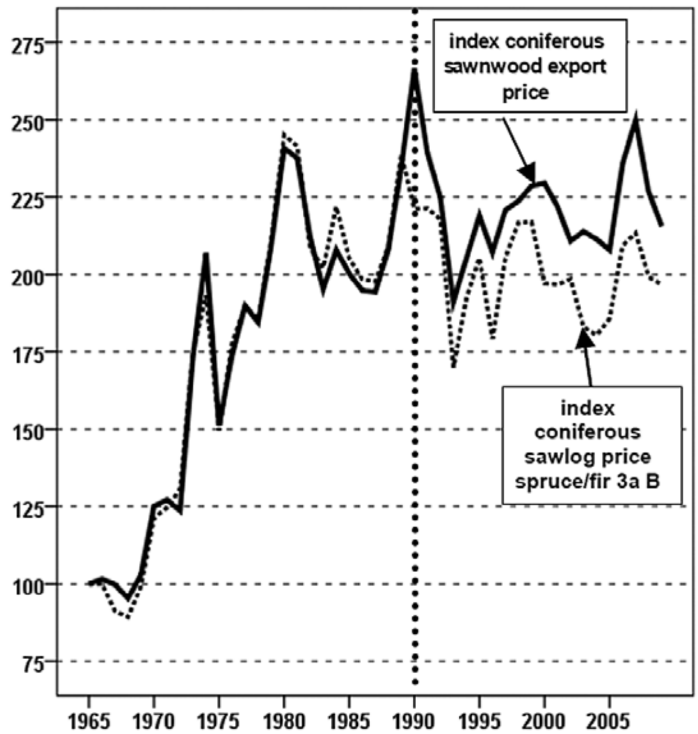

Figure 18. Indices of nominal coniferous sawlog price (spruce/fir 3a B) and nominal coniferous sawnwood export price over time (indices: 1965=100).

only have a moderate impact on sawlog prices (and almost none on pulpwood prices). But this should not hide the fact that single, extraordinary storm events can have strong price depressing effects in single years and can also lead to a long-term downward shift of the sawlog price level in comparison to sawnwood prices.

Storms also have considerable impact on wood procurement in the long term.

In addition to the direct impacts on roundwood prices storms considerably change the modal split of transportation (proportions of wood transported by truck, train or inland vessel). After a storm a huge amount of salvage wood has to be harvested and transported in a short time span in order to prevent severe wood quality losses and proliferation of forest insect pests. Usually trucks in the affected region are soon working to capacity and multimodal transport (two or more transportation modes, e.g. truck and train) is increasingly used, since rail and water transport offer high transportation capacities and, salvage wood is often transported to more distant industry facilities compared to regular supply situation. The latter mainly occurs because of the low roundwood prices and huge volumes forest owners have to get rid of very quickly. Depending on the salvage wood volume, changes in bucking patterns, transportation and allocation of wood can last for months or even 2 or 3 years after extraordinary events like the Storm Gudrun in Sweden.

A recent study has developed a forest sector simulation model that assesses long term effects of storms and bark beetle outbreaks on the wood supply in Austria. The model follows the physical wood supply from the standing tree to the forest-based industry as well as to the energy industry. It integrates decisions of the forest owners on planned harvest, divided into thinnings and final cut volume. The simulated harvesting process includes bucking decisions depending on market prices and wood quality requirements. Forest damage from storms or insect outbreaks is included in the model and can interrupt the fulfilment of the harvest plans. The damage is included in the model in a stochastic manner that replicates forest damage due to storm and bark beetle outbreaks in Austrian forests over the period 1973 to 2009.

In addition to this baseline scenario a climate change scenario was tested which reflects the increasing vulnerability of Austrian forests and thus the increasing risk of forest damages. The parameter setting is the same as in the baseline scenario except that the frequency curves of forest damages due to storm and bark beetle outbreaks were fitted to the data for the period 1990–2009 because there were higher levels of forest damage during these two decades. The results, such as the annual domestic supply rate are shown in Figures 19 and 20 and represent the probability of a certain outcome.

In the baseline scenario, there is only a 35% probability of the domestic supply rate of sawlogs being lower than 60 percent of the annual demand. In Austria, the average import rate of sawlogs is about 40%, therefore a 60% domestic supply coverage can be seen as a secure supply situation. The domestic supply of pulpwood is for 90% of all cases higher than the 60% demand from the annual pulpwood supply (Figure 20). This very secure pulpwood supply situation is a result of the fact that the forecasts of the production volume increase of the Austrian sawmill industry is considerably higher than those of the domestic pulp and paper industry. Although the climate change scenario includes more frequent and intensive forest damage events with a considerable

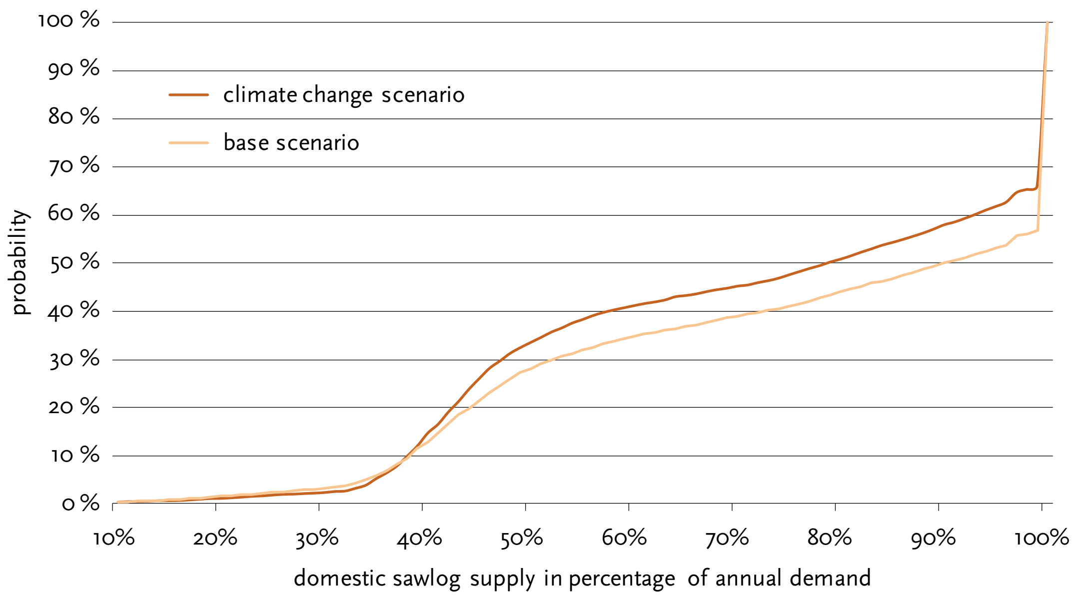

Figure 19. Cumulative distribution function (CDF) for Austrian domestic supply of sawlogs for the period 2010 to 2030.

increase of salvage wood, the sawlog supply situation becomes worse over time, because the probability of a domestic supply rate lower than 60% increases from 35 to over 40% (Figure 19). Furthermore, the domestic pulpwood supply will face a moderate increase of import requirements but the probability of undersupply stays stable at a very low level (Figure 20). In summary, the short term surplus wood supply after a storm event will be dominated by a significant reduction of harvest activities or even complete cessation in the same or the following year(s), leading to a supply shortage in the medium term.

These simulation results stress the need to develop strategies to overcome periods of massive undersupply. One promising strategy is to store roundwood for a longer time period by constantly sprinkling the piles with water during the vegetation period or by shrink-wrapping wood so as to keep it airtight in order to prevent attack of wood destroying pathogens or insects.

Future procurement strategies and policies need to include the removal of roundwood quantities from the market as a consequence of storm effects.

As a general rule to absorb sudden and negative roundwood price shocks due to storm events, measures can be recommended that dampen the shift of the supply curve to the right or even prevent the shift at all (see Figure 17). In particular storage facilities that take roundwood quantities out of the market (at least for a period) and reducing roundwood imports and increasing exports can be valuable.

Storms and their medium term effects are usually not considered explicitly in industrial wood procurement strategies. Simulation results for a procurement period of ten

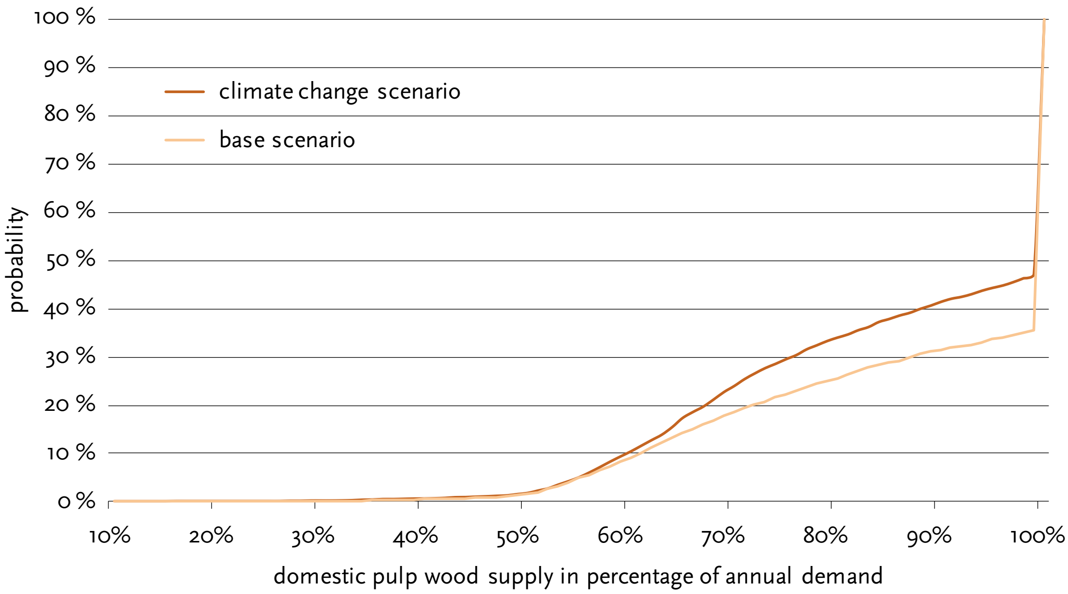

Figure 20. Cumulative distribution function (CDF) for Austrian domestic supply of pulpwood for the period 2010 to 2030.

years in Austria indicate that supply chain risks from undersupply can be reduced and procurement costs are about 3% less than normal delivery costs if storms and their medium term effects are included in the procurement strategy and wood is stored after exceptional storm events.

We conclude that including risk, with storms as the most important risk agent, in the evaluation of wood supply chains provides a robust basis for strategic procurement decisions.

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3.4.

Societal impacts of storm damage

Kristina Blennow and Erik Persson

Wind damage to forests can be divided into (1) the direct damage done to the forest and (2) indirect effects. Indirect effects may be of different kinds and may affect the environment as well as society. For example, falling trees can lead to power and telecommunication failures or blocking of roads. The salvage harvest of fallen trees is another example and one that involves extremely dangerous work. In this overview we provide examples of different entities, services, and activities that may be affected by wind damage to forests. We illustrate how valuation of the damage depends on the perspective applied and how the affected entities, services, and activities may represent different types of values. Finally we suggest means for how to actively manage the risk in an ethically sustainable way. Many of our examples will be drawn from the experiences of the wind damage Gudrun in southern Sweden on 8–9 January 2005. The direct as well as indirect effects, which are described, are by no means unique to the Gudrun wind damage event and similar or even worse effects have been described after the wind damage events Martin and Lothar in 1999, and Klaus in 2009.

The Gudrun wind damage event on 8 January 2005

On the evening of 7 January, 2005, a low-pressure system formed northwest of Iceland. At mid-day of 8 January the center of the low-pressure system reached southwest Norway and the wind speed increased to gale force on the Swedish west coast. The peak in the storm was reached somewhat later during the same day and during the following night when the low-pressure system passed Sweden it had developed into the most damaging weather event known to occur in Sweden. Damage of different kinds was done also in other countries along its path; from Great Britain to the Baltic States and Finland. The total volume of forest damaged was largest in Sweden while the fraction of the total growing stock damaged was largest in Estonia (Figure 21).

Impacts on society

From a Swedish timber and wood production perspective the Gudrun wind damage event resulted in damage to forest corresponding almost a full year's Swedish harvest. But the damage done to the Swedish forest was done in a limited part of the country (Figure 22). Even though at a Swedish national level the impact was big but manageable, at a local level it was devastating. In the affected region approximately 80% of the productive forest area was owned mainly by private individuals.

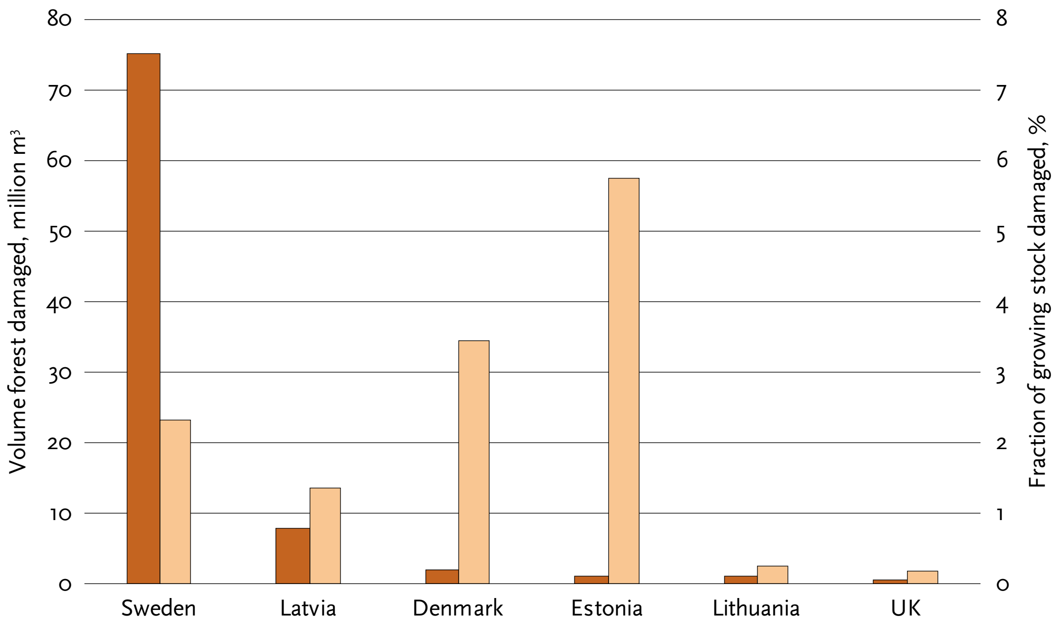

Figure 21. Damage volumes and percentage of growing stock by country for the 'Gudrun' wind damage event on 8–9 January 2005. Darker bars indicate volume of damage, lighter bars fraction of growing stock.

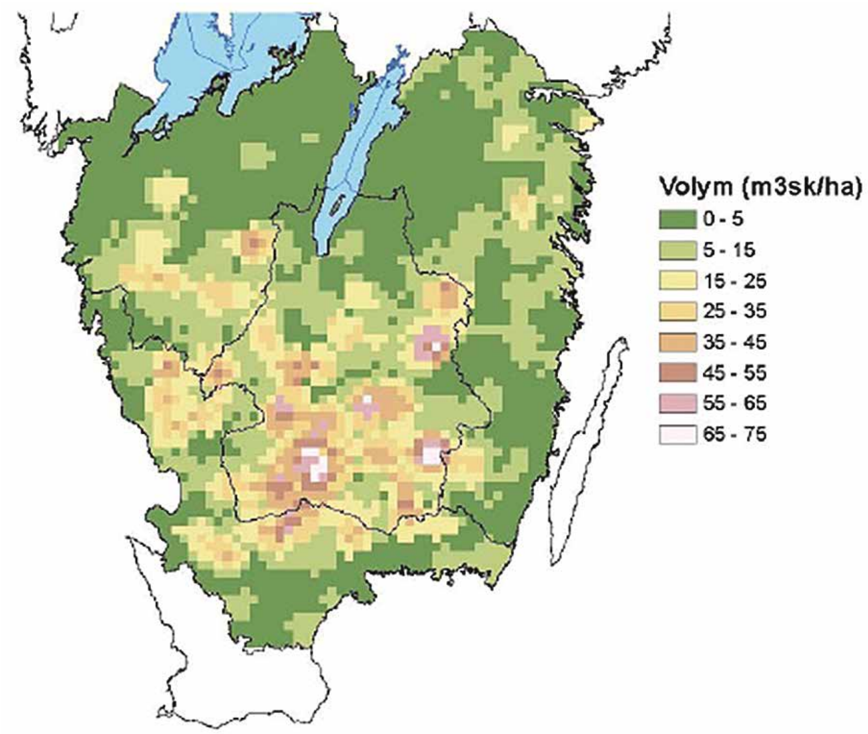

Figure 22. Damaged volume (m^3/ha) in southern Sweden after the 8 January 2005 wind damage event based on visual inspection from aircraft (from SFA, 2006).

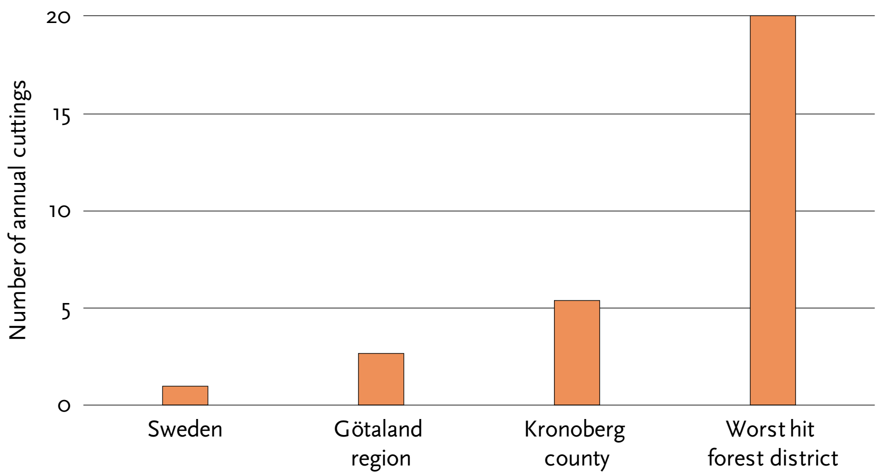

Figure 23. The volume of forest damaged by the storm Gudrun divided by the annual cutting volume for the corresponding area.

In the most extensively damaged forestry district the damage corresponded to more than 20 annual harvests (Figure 23). Here, individual land-owners saw their forests devastated (Figure 24).

The forested landscape provides a plethora of entities, services, and activities that can be affected by wind damage. The region of Götaland was the most affected by storm Gudrun and had 3.9 million inhabitants (43% of the Swedish population) in 2005. The directly affected individuals were mainly found among those living in the countryside.

The fallen trees resulted in a peak of timber and wood to be harvested, transferred to and used in the industry. While this in turn resulted in job opportunities, the fallen trees damaged and blocked infrastructure. For example, 300,000 Swedish subscribers' non-mobile telecommunications systems were not functioning, and two months later a large number of subscribers were still without telecommunications. The mobile systems and data-traffic was also severely affected. Furthermore it took 34 days before all railway lines in the region were in use again. With respect to power-failures, approximately 730,000 subscribers were affected. Some areas were particularly difficult to reconnect, and customers suffered failure for up to 45 days after the storm. The implications were particularly important for the maintenance of civil security. A large number of people became isolated and during the night of the storm many of the municipal officers on emergency call worked under high risk. For example, home medical service personnel exposed themselves to high risk when they, sometimes under escort from rescue service personnel, tried to reach patients that were without electricity and telecommunications. The lack of heating due to power outage made people use old and non-functional stoves for heating which in turn resulted in fires. The power failure also caused severe problems

Figure 24. Wind damage after the storm Gudrun in southern Sweden on 8 January 2005. (Photo by Kristina Blennow)

for dairy farms. At this time, the Swedish security system was stretched to its limits and there could have been more severe consequences had not favourable circumstances, such as mild weather, mitigated the situation.

In Lithuania during the same storm fallen trees caused an almost complete collapse of the power supply, leaving 1.4 million people without electricity. While in Lithuania for most subscribers the power was back within a week, power outage caused a 23 days long emergency situation in Latvia.

After the Gudrun wind damage event the landscape was dramatically changed in many ways. There were reports that people were unable to find their way home in areas where they had spent most of their lives, and people had to cope with the forest that they had spent a life-time tending being destroyed. Some individuals have been reported even to have committed suicide because of the devastating consequences of the storm. One year after the storm approximately one third of the respondents to a questionnaire to private individual forest owners in the affected part of Sweden claimed that their well-being was reduced.

Wind is an important dynamic factor for forest ecosystems with the areas affected by wind damage ranging from small-scale gaps to large-scale tracts. Recently it has been shown that the wind exposure also affects the remaining forest; the growth of the remaining spruce forest in the affected region in Sweden was reduced by 3 mill. m^3 during the three years following Gudrun. The impacts of wind damage to forest on the biodiversity depend to a large extent on the post-storm management. The changes will affect both fauna and flora and wind felled logs in the forest may reduce access to the forest for activities such as mushroom and berry picking which are highly valued activ-

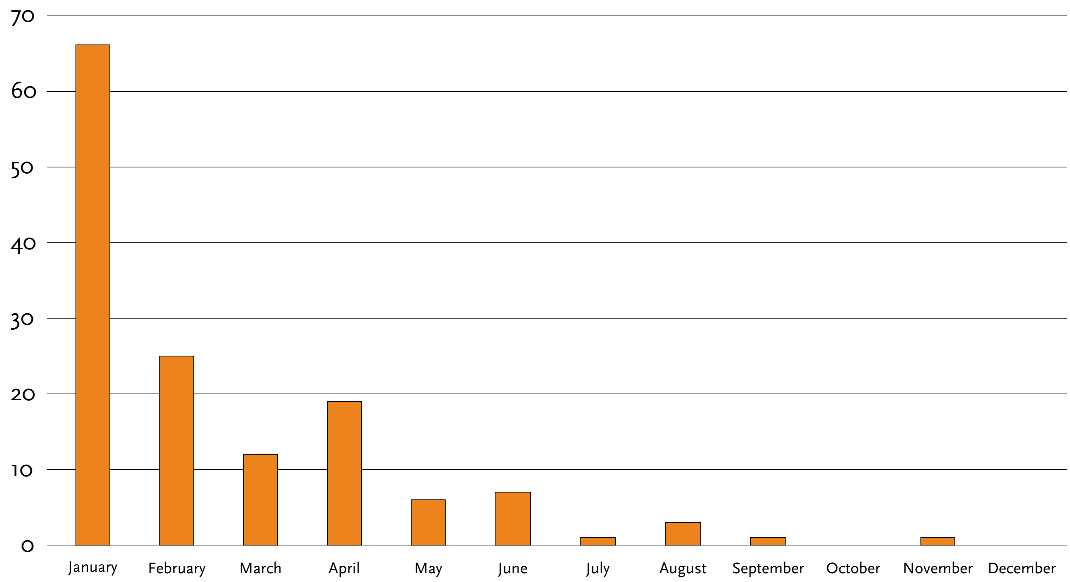

Figure 25. Number of accidents to Swedish workers in clear-up after the 'Gudrun' storm damage in Sweden during 2005. Data source Arbetsmiljöverket.

ities in many European countries. At present we don't know to what extent wind damage affects the availability of berries and mushrooms but recreation activities such as trekking and sport in the forest can be disrupted, generating losses in the local tourism sector. In contrast the availability of game for hunting may increase after a wind damage event. Road accidents have been reported to increase as a consequence of larger game populations resulting from higher availability of food in wind damaged areas.

Accidents

Accidents and casualties from wind damage to forest result both directly from falling trees, and indirectly from work in salvage harvesting, work in association with repair of damaged infrastructure, and because of consequences from power failure caused by fallen trees. Seven people were killed in Sweden by falling trees and other objects during the night of the Gudrun storm. The clean-up work after a wind damage event often involves extremely dangerous work (Figure 25). Indeed, the number of reported accidents per volume harvested timber in Sweden was double in 2005 to that in the year before the storm. During 2005, 141 working accidents were reported from the clean-up work and up to January 2006 11 fatal working-related accidents had been reported. The number of accidents is, however, likely to be underestimated since workers involved in accidents are known often not to report the accident.

Furthermore, only accidents by individuals registered in Sweden are included in the statistics for Sweden even though workers from several countries were involved in the salvage work.

The utilitarian versus the rights-based approach to valuation and risk-taking

A risk is usually conceived of as a combination of probability and effect. The probability tells us how likely it is that something will happen. The effect tells us the importance of the consequences if it happens. If a risk is large or small is thus a question both of how probable it is that something will happen, and how important the consequences. Risks and possible benefits can then be weighed in different ways. If our aim is only to maximize the total amount of benefits and minimize the total amount of negative effects for the whole population, it is called a utilitarian approach. If we include other things such as a fair distribution, respect for individual rights or the dignity of our acts as such among our aims, we call it a rights-based or deontological approach.

Risk is the combination of the probability of a damaging event and the consequences if such an event occurs. The impact and value of the consequences depends on who is making the judgement and could be very different for a private individual, a forester, a sawmill owner, or the regional or national governments. Therefore, even though the probability of a damaging event is the same for everyone, the risk will be different.

Storms do occur from time to time. There is not much we can do about that. Storms may even get more common with climate change and the sensitivity of the forest to wind is expected to increase with climate change. Hence, the probability of wind damage is expected to increase. Sometimes people take a defeatist approach to wind damage. The probability of wind damage is, however, strongly dependent on the way we manage the forest, and we do have plenty of opportunity to modulate the probability of wind damage to the forest. We could even remove the risk of wind damage by cutting down all trees if we wanted to. Forest management options for modulating the probability of wind damage include choice of silviculture system, spatial planning, modification of the thinning regime, and the choice of tree species, as described in more detail in Chapters 2.3 and 4.2.

How negative are the consequences of the wind damage is obviously a matter of valuation. The valuation of the wind damage can be done in different ways. When the society is weighing risks and benefits it generally takes a utilitarian approach, meaning that it concerns itself with the total sum of good and bad effects for the whole society. The valuation of the direct effect of wind damage to forest is traditionally made in this way for instance in terms of the percent of national growing stock damaged by wind.

Risks and benefits are however rarely distributed equally through a society. If the national growing stock is large, even extensive local damage will amount to only a small fraction of the national growing stock. If we look again at the effects of the Gudrun event, we notice that it damaged only 2–3% of the total growing stock of forest in Sweden, and the damage was concentrated in a small part of the country (Figure 21). When we look at the access to timber for the industry and the costs to society (i.e. the taxpayers) it makes sense to take an overall view. We then discover that the effects were noticeable but not devastating. If we however look at other effects such as the financial effects from loss of revenues, being without electricity or communication for several weeks, the emotional costs of seeing a forest you have spent your life tending being wiped out in one night, or even being crushed under a falling tree, the picture is very different. In these cases it does not seem to make sense to look at the total or even the average costs since in fact a small (relative to the whole population) number of people had to bear the entire burden, and that was in many cases a devastatingly large burden for an individual.

Values at stake

To claim that something has value can in fact mean many different things. It is often convenient to as far as possible express all values in monetary terms since by doing so it is possible to weigh them on the same scale, and to fit them into existing accounting systems. This is, however, not always possible and it is commonly acknowledged that there is no perfect way of doing this. One reason for this is that not everything is or can be sold for money on a market. Take for example the relationship a forest owner has with a forest he planted together with his grandfather and that he has lived with all his life and is now tending with his granddaughter. Something that cannot be sold on the market means that putting a monetary value on it will be somewhat artificial and it is not clear that it can be measured on the same scale as something that has real monetary value because of real transactions in a real market. Another problem with translating all kinds of value into monetary value is that we lose information in the process. There can be many different reasons why someone wants to buy something on the market. It might be because she values it as an end in itself, because she sees a value in it as a tool for achieving some other value, or because she expects you to value it and plans to sell it to you. All these motives can be transformed into a demand on a market and measured in monetary terms, but when planning our own lives as well as our everyday decisions it is still useful to distinguish between different motives. The same goes for those who are in charge of a community or a whole country. We believe it is of particular importance to distinguish between instrumental values and end values. That something has an end value means that it is valuable as an end in its own right. You might say that it is the ultimate goal of your act or decision – the thing you value not because of what it can further accomplish but for what it is in itself. An instrumental value then is something that only has value because it helps you to accomplish your end values.

Ethically sound risk management

For so long as we want to have forests there will be a risk of wind damage. To actively manage the risk we need to understand the causal relationships (Chapter 2), how we can modulate the probability of wind damage (Chapter 4.2), and what are the effects following inaction as well as action (Chapters 4.1 and 4.3). But we also need to clarify what are the ultimate consequences of our decisions. To avoid regretting a decision if the risk materializes, it is rational to consider different possible future states, including the undesired ones before coming to a decision. Our causal knowledge then gives us the opportunity to prioritize between management options and to choose an option so that we can avoid situations in which our ultimate ends are not fulfilled. Sometimes one has to come to a compromise and that can only be done by the individual from his or her own subjective perspective.

As we have seen, wind damage to forests has effects that reach outside of the forestry sector. This means that to be able to manage the forest in a sound way we need to consider not only the volume of timber and wood that is at risk of being damaged but also what type of values are at risk and for whom. We also need to openly discuss what ethical basis we use for our decisions. As we noticed above, values and damages are usually weighed in a utilitarian fashion. This might, or might not be the best way of doing it but we believe it should be clearly stated and open for debate and improvement.

Whether we use a utilitarian approach and aim only for maximizing the total value, or if we also want to find a fair distribution of value, or a solution based on respecting certain basic rights, we will need some way of dealing with the sometimes rather complex and entangled web of different values that are at stake. As we have seen, the method of coding all values in monetary terms is very useful for making comparisons but it has drawbacks. This is not a reason to abandon the idea however. Instead, we need to complement it with a method for keeping track of the different kinds of values involved, and of the relations between them.

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4.

Response and Prevention

4.1. Mitigation of forest damage

Barry Gardiner and Peter Welten

Risk management

Damage mitigation is part of the wider process of risk management in forests (see Figure 26). It attempts to analyse the level of risk, and then respond to this risk by acceptance of the risk (make no changes to the management plans), by risk reduction (reduce the probability of damage or the value at risk) or by risk sharing (e.g. through insurance). It has to be part of a continual process of evaluation and assessment before and after damage events that seeks to determine what changes in management or risk sharing/spreading are required and to implement these changes if required. It is a strategic level response that complements the immediate response following a storm described in Chapter 4.3. These two types of response need to be considered together so that implementation of one does not hinder the successful implementation of the other.

Damage mitigation is the part of forest management that attempts to prevent damage occurring and to reduce the impact of a potential hazard event. It is part of the four phases of disaster management: Mitigation → Preparedness → Response → Recovery. It has two distinct components:

- structural response that reduces the risk through risk analysis and implementation of risk reducing policies and practices, and
- non-structural response that help spread the economic impact of an event through, for example, forest policy and insurance schemes.

Risk analysis

In order to develop a mitigation policy it is first necessary to have a way to analysis the level of risk and ideally to be able to predict the impact of any changes to the management of the forest. Without some form of risk analysis the value of any mitigation policy can only be guessed at. Currently there are two forest wind damage risk models operational in Europe, “ForestGALES” and “HWIND”, which are both hybrid mechanistic-

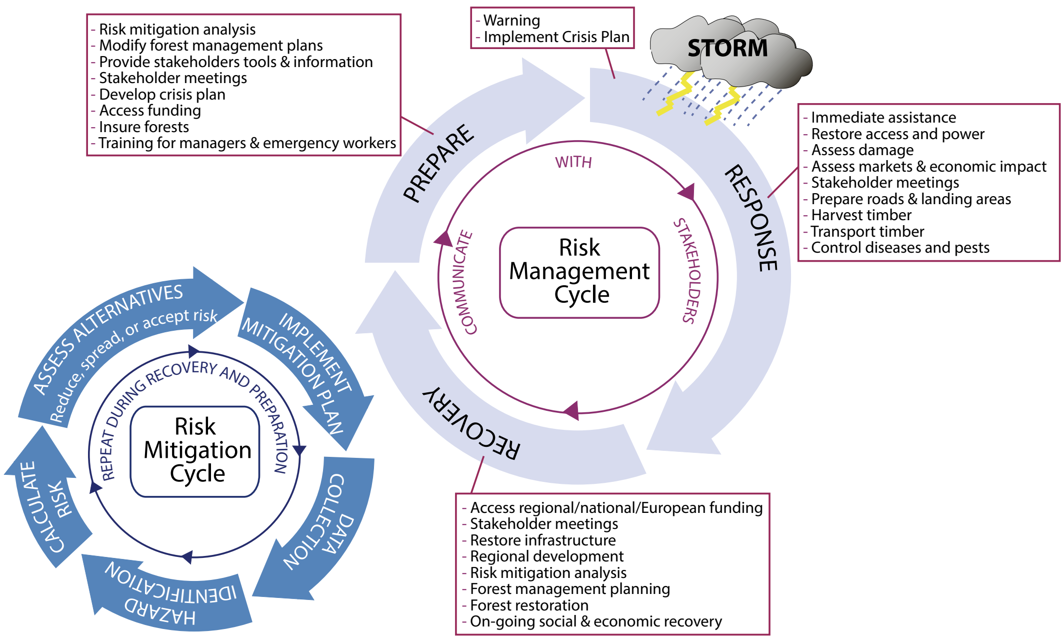

Figure 26. Mitigation as part of the risk management process. Courtesy of Kana Kamimura.

empirical models. The development of such mechanistic models is described in Chapter 2.2. Another approach is to develop purely empirical models based on inventories of past damage. They require large amounts of high quality data across a range of conditions and may only be useable in the area from which the inventory data were obtained and for the type of storm that the analysis is based on. An example of such a model is "Lothar" which is based on a detailed inventory of around 1300 plots following storm damage in the Black Forest in 1990 and 1999. Further details of this approach can be found in Chapter 2.3.

In addition to calculating the probability of damage it is also necessary to provide a measure of the value or exposure associated with the forest at risk because risk is a combination of the probability of damage and the value at risk (exposure). The value will vary depending on the particular stakeholder (general public, forest manager, forest owner, regional government, etc.), what they value, and what are their objectives. Further details of how forests are valued are presented in Chapter 4.4.

Planning and implementation

Following an analysis of the level of risk there are 3 possible responses:

1. Reduce the Risk: If the risk is too high to be acceptable then a strategy for reducing the risk can be implemented. This is normally through forest management and is discussed below and in detail in Chapter 4.2.
2. Spread the Risk: The impact of storm damage can be reduced by spreading the risk. This can either be by having a diverse portfolio of forest types and/or forest locations or by sharing the risk with other stakeholders through some sort of insurance scheme. This is discussed in more detail below.

3. Accepting the risk: If the risk of storm damage is low or the cost of mitigation outweighs the benefits, the most sensible strategy may be to accept the risk and prepare plans for responding to the aftermath of a storm.

In all cases a key part of the mitigation strategy is to ensure that plans are in place for dealing with the consequences of a storm. Without prior preparation and immediate crisis response (see Chapter 4.3) the risk mitigation strategy is of no benefit.

Forest management

The risk of wind damage is a combination of exogenous factors (external factors such as wind speed which cannot be controlled) and endogenous factors (internal factors that can be controlled). The most direct way to manage the endogenous factors is to adapt the management of the forest. Chapter 2.3 discusses the factors that have been found to influence levels of wind damage and Chapter 4.2 outlines the forest management responses that can reduce the vulnerability of a forest. It is important to realise that under circumstances where the overall risk is low (e.g. benign wind climate or low value product) the cost of any mitigation action may not be justified, and similarly where the risk is very high (windy climate or very high value product) the economic consequences of any mitigation management (e.g. reduction in rotation length or value of the forest) may not be justified by the reduction in economic benefits (see Figure 27). It is when the risk is intermediate that mitigation through forest management can have the greatest benefit. In the area of intermediate risk, small reductions in vulnerability (i.e. small increases in critical wind speed) through careful management can produce a dramatic reduction in the probability of wind damage because of the shape of the wind probability distribution curve. Similarly, small increases in vulnerability such as by not unblocking drains, or by thinning too late or too heavily, can produce a marked increase in the probability of damage. For example, a 30 year old fast growing Sitka spruce forest in Brittany on the North-west coast of France (see example in Figure 27) with a critical wind speed of 27.5 ms^{-1} would have a return period of between 20 and 33 years. Increasing the critical wind speed by 2.5 ms^{-1} to 30 ms^{-1} would increase the return period to over 100 years but decreasing the critical wind speed to 25 ms^{-1} would reduce the return period to less than 10 years.

Of course risk changes with time and generally forests move to higher vulnerability (lower critical wind speed) with increasing age and height (see Chapter 2.3). Therefore, management needs to take account of risk over the future lifetime of the forest and not just to focus on one point in time. Risk mitigation strategies need to calculate the risk over the whole rotation and to balance the cost against any benefit. For example, although early thinning may have a cost and make a stand slightly more unstable for a few years after thinning, the overall risk for the lifetime of the trees will be reduced. Similarly replacing one species with another that is believed to be less vulnerable, may not be a benefit if there is an economic cost of such a choice, or the time taken for the alternative species to reduce maturity means that it spends many more years at risk compared to a faster growing species (i.e. it has a higher cumulative risk). The strategies followed will depend on the point of view of the stakeholder and whether they are risk neutral, risk averse or risk taking (see Chapter 4.4). It will also depend on the management objectives. If the primary goal is to maintain tree cover then cost may be a secondary issue

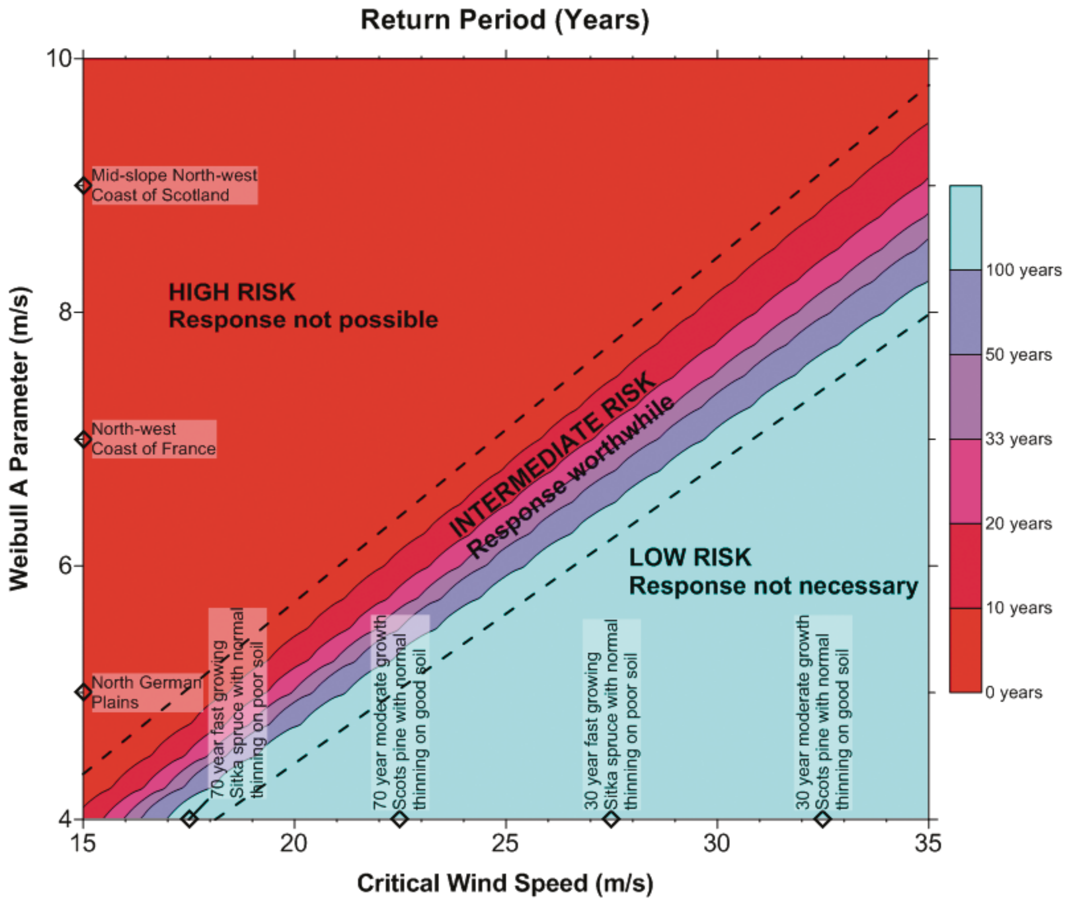

Figure 27. Average number of years between damaging events for forests of different vulnerability (example critical wind speeds are shown on x-axis) and with different wind climates (example wind climates shown on y-axis). The Weibull A parameter is a parameter for describing the wind climate and is approximately equal to 113% of the mean wind speed. Risk mitigation must take into account the level of risk, and generally a direct management response is only worthwhile for forests at intermediate risk.

and owners may be willing to invest a considerable amount of money to gain small increments in vulnerability reduction. If the primary goal is economic then any expenditure on reducing risk will need to be balanced against any economic benefits (e.g. reduction in losses, higher timber values, and longer rotations).

Forest management can successfully reduce the risk of wind damage and can be enhanced through regional and national forest policies and certification schemes. The most effective management is in forests at intermediate risk. Mitigation policies are unlikely to be effective in forests at high risk and are not usually necessary for forests at low risk.

Spreading risk

An important mitigation strategy is to spread the risk. This can be achieved by having forests over a wide range of geographical locations, having a mixture of stand ages (either between stands or within stands) and a mixture of tree species. It is a strategy that is likely to be easier to implement in a large scale forestry operation such as an investment company or a state forest service because of the diversity of their forest portfolio. However, even a small-scale forest owner can spread his/her risk by using a number of species and by adopting a system of management that encourages a diversity of tree sizes and ages such as continuous cover forestry (see Chapter 4.2). In addition it is also possible to "hedge one's bets" by managing some stands for a high economic return but with a high risk of damage, while keeping other stands at a lower risk but with an acceptance of a lower economic return. In this way, if wind damage does occur, the whole forest estate is not affected equally and the overall damage level is reduced.

A second method of spreading the risk is to share the risk through collaboration with other stakeholders rather than active management of the forest. This is usually through some form of insurance scheme or through regional or central government policies on forestry and forest restoration and is discussed in the following section.

Insurance and restoration funds

Insurance against wind damage is available in most European countries. This usually covers re-establishment costs (the only form of repayment in younger stands), compensation for timber losses, and the additional cost of harvesting. However, additional fuel costs in transporting timber to storage sites or long-distance markets and losses for reduced timber prices are usually not covered by insurance. The major difficulties for insuring against wind damage are calculation of the correct premium, awareness and willingness for forest owners to purchase insurance because of their perception of a low risk, and the fluctuating value of timber. In addition the low frequency but high severity of wind damage means that there will be very infrequent but very large claims, which can overwhelm insurance and reinsurance companies when the storm is catastrophic (see Chapter 3.2).

Some emergency funds to deal with storm damage are available through the European Union Solidarity Fund but this is designed to fund immediate crisis management and clean up, but not to cover private losses. However, Article 48 of the European Agricultural Fund for Rural Development (EAFRD) states that "*support shall be granted for restoring forestry potential in forests damaged by natural disasters and fire and for introducing appropriate prevention actions*" and could be used for forest restoration following storm damage. Some governments and regions have funding mechanisms permanently in place to help restore the forest after storm damage but there is currently neither a systematic system across Europe nor any direct link to the insurance sector.

A complementary arrangement of private insurance, regional, national and European emergency response funds could provide an effective mechanism for mitigating the financial impact of storm damage and enable the forests and the forest owners to recover quickly (see Chapter 4.3 for more detail on forest recovery). There is a clear need for some form of standardised storm insurance system across Europe partly underwritten by national governments and European contingency funds. However, this is not straightforward because different European states have different attitudes to helping forest owners after storm damage. Importantly there needs to be an incentive to forest owners to arrange some form of insurance and not to rely only on state subsidies if a catastrophic storm occurs[1]. These issues are discussed in more detail in the concluding section to this book (Chapter 5.3).

Successful mitigation of the financial impact of wind damage to storms requires a co-ordinated link between private insurance, regional and national forest restoration funds and European Union level emergency funding.

Policy instruments

Active policy instruments that encourage good practice have been shown to be effective in ensuring that policies are implemented for the overall good of the forest sector and for helping the sector to respond to the consequences of storms. Experience from Switzerland has shown that the economic recovery after Storm Vivian was more effective in Cantons in which there was direct engagement and financial assistance by public authorities than those in which there was little financial assistance. Forest policy can also help to ensure good practice and avoid individual owners pursuing policies that adversely affect their neighbours. Examples would be owners not clearing wind damaged timber from their land leading to large infestations of bark beetles in neighbouring healthy forests, or making large clear fell areas upwind of a neighbour's forest, which puts the newly exposed neighbouring forest at higher risk of wind damage. Such policies will be extremely important but difficult to implement in regions with large numbers of small-scale forest owners.

In the United Kingdom policy within the public forest estate has restricted thinning in stands within areas of high average wind speeds and sets target heights (critical heights) for harvesting stands based on the risk of wind damage. Such policies have been developed based on the experience of a number of severe storms following extensive re-afforestation during the 20th century. The result has been that wind risk management is fully integrated into forestry in the UK and has been effective in reducing wind damage. However, the system is conditioned by the severity of damage from those initial events and the system may be too restrictive compared to other countries and illustrates the need to continually re-evaluate policy following damage and to adjust approaches to mitigation.

The cumulative effects and experience of Storms Wiebke, Vivian, Lothar and Kyrill, and Storms Lothar, Martin and Klaus in Germany and France respectively have led to the production of comprehensive regional and national material for assisting forest owners in dealing with the aftermath of storms and adapting their forest management. Excellent examples of comprehensive web-based material provided to aid forest managers can be found at http://www.waldwissen.net/waldwirtschaft/schaden/sturm_schnee_eis/index_EN and http://www.foretpriveefrancaise.com/quelques-conseils-479391.html. These give straightforward and practical information on dealing with the after-

1 New forest laws in France will only provide state funds for forest restoration for owners with their own insurance (after 2015).

math of a storm and accessing financial assistance to re-establish the forest. Such systems, which provide best practice guidelines and information, are extremely helpful in preparing ahead of storms and reducing their impact.

Certification schemes, such as FSC and PEFC that are now widely adopted across Europe can also be of benefit by promoting good management practice and encouraging maintenance in forests. These schemes could be used more directly to encourage owners to make risk management and integral part of forest management as outlined in Chapter 4.2.

Risk perception

One of the most important requirements for the successful implementation of risk mitigation strategies is how the risk is perceived by stakeholders. Risk perception will vary between the forest owner, forest manager, forestry authorities and the public because of their different objectives with regard to the forest, the values they place on the forest, and the information available. The levels of risk aversion will be conditioned by previous experience and may be significantly biased towards adopting a low risk strategy if there has been recent experience of damage or towards a higher risk strategy if there is little experience of catastrophic damage. Such matters are dealt with in more detail in Chapter 4.4.

In many places in Europe there was little experience of severe storm damage before the series of extremely damaging storms between 1990 and 2009 that affected in particular Southern Sweden, Denmark, the Low Countries (Netherlands and Belgium), Central Europe (Switzerland, Germany, Czech Republic) and France. In many places there was no active wind risk management within the forests and often levels of insurance were low. This led to very high levels of damage and financial loss, which many of these countries are still dealing with. In order to reduce the probability and impact of future wind storms it is necessary to make risk management a normal part of forest management. This allows the levels of risk to be calculated and reasoned mitigation strategies to be put in place that balance the level of risk against the financial cost of these strategies.

Risk management needs to become an integral part of the management of European forests.

Risk mitigation is a key component of risk management which identifies the level of risk, assesses alternative strategies and implements risk reduction strategies.

Opportunities

The process of conducting a risk mitigation analysis allows the forest owner, forest manager and local policy makers to evaluate the objectives for the forest and to determine if any management changes are necessary. It can provide the opportunity to instigate a new strategic approach, which has a higher probability of delivering the desired outcomes from the forest over the long term (see also Chapter 3.4).

Conclusions

Mitigation for the effects of wind on forests is possible through three strategies. The first is to manage the forest in a way which reduces the risk through direct stand treatment in order to reduce forest vulnerability and exposure. The second mitigation strategy is to spread the risk within the forest or across the forest estate in order to reduce exposure, or to use private insurance and regional/national/European emergency funding to spread the cost of a catastrophic wind storm event. The third approach is to accept the likely losses of a damaging storm because the cost of mitigation is too high compared to the benefits, but to still prepare for the aftermath.

All three approaches require access to risk assessment tools for determining the level of risk and to calculate the cost to benefit ratio. Risk mitigation is also fundamentally dependent on the risk perception of different stakeholders and it is important that the true risk and benefits of mitigation are made clear to decision makers. Mitigation is of no long-term value if it is not part of a cycle of improved preparedness, an ability to respond, and affective recovery mechanisms, which are part of the overall risk management of the forest. Therefore, mitigation is closely linked to preparing for a storm and the implementation of appropriate crisis response measures. Only effective preparation and immediate response following a storm can mitigate the short and long term impacts on the forest.

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4.2.

Managing forests to reduce storm damage

Bill Mason and Erik Valinger

Damage by wind occurs regularly but can be minimized by

- silvicultural measures, such as choice of species, cultivation, drainage, spacing and thinning,
- design and management of forest edges,
- diversifying the structure and composition of the forest

Introduction

The effects of wind disturbance in forests can occur at a range of scales, from the overturning of an individual tree through the blowing over of small groups of trees to catastrophic damage where trees are blown down or broken over many hectares. The ability of forest management to influence the occurrence of wind damage will be limited if a particular forest lies directly in the track of an *extreme* storm (e.g. Lothar, Martin, Gudrun, Klaus), which will result in extensive damage with major consequences for the sector (see Chapters 3.4 and 4.3 for definitions). However, the resilience of a forest to *normal* winter storms will be influenced by the silvicultural regimes that have been used in previous decades. For example, stands where thinning has been delayed or are growing on wet soils where the trees have shallow root systems as a result of neglected drainage may prove particularly vulnerable to windthrow. By contrast, stands of wide spaced trees on deep rooting soils that have been well thinned should show greater resistance to the wind. Therefore, a prudent manager will take steps to implement silvicultural practices which limit the potential vulnerability of forests, even if no major storms have occurred for several decades. The aim of this chapter is to highlight those aspects that forest managers should consider in order to reduce the impacts of wind damage.

Climate and site knowledge

There are at least three **permanent** factors which affect the risk of wind damage in a forest or region. These are the climate of the region, the topography and terrain where the forest occurs, and the soils present in the forest. Taken in combination, these factors set the framework within which silvicultural measures can be used to reduce the risk of wind damage. These factors vary substantially across Europe and are a major reason why management practices that are successful in one region cannot be transferred to another without testing and adaptation.

The first factor is the wind climate and history of the particular area in which the forest is located. The probability of a major storm will be much higher in the Atlantic region than in lowland areas of central Europe, but damaging storms have been reported in the last 60 years from countries with apparently benign wind climates such as Ukraine and Romania. Therefore national meteorological records should be examined to assess the likely risk from damaging wind speeds. Given the potential impact of projected climate change, this examination should also assess the possibility of a higher frequency of major storms or of increased winter rainfall and wet snow events, which will all influence the risk of future damage.

The next factor to consider is the terrain, and in particular whether the topography is likely to influence the exposure of the forest to damaging winds. In complex terrain winds can be funnelled along valleys and accelerated, causing severe damage to stands on mid slopes. Stands that are on east facing slopes sheltered from the prevailing wind (generally north-west to south-west in Atlantic Europe) will generally be at less risk of damage than those in more exposed locations, although turbulence can sometimes cause damage further down the lee slopes of ridges (see Chapter 2.1). In more regular terrain, stands on plateaux can be more vulnerable than those on slopes, although the occurrence of damage will also depend upon soil type. Methods of assessing site exposure such as Topex[1] can be helpful in classifying a forest into zones that are more or less sheltered from the wind.

A good soils map is necessary for assessing those parts of a forest that may be at risk from damage, as well as for many wider aspects of sustainable forest management. The map should be at a scale of 1:10000 or less, and needs to particularly identify those soils which are likely to cause restrictions upon tree rooting and anchorage. Examples include surface water gleys with high winter water tables, ironpan soils, and shallow soils (<40 cm) over rock. Local surveys may be necessary in complex terrain where poorly drained pockets of wet soils (e.g. peats) alternate with well-drained podsols on glacial moraines.

General silvicultural measures

There are a number of stand level silvicultural decisions which can influence the incidence of wind damage. These include species choice, site cultivation and drainage, the type of planting stock used, the spacing at which trees are established, the timing and intensity of thinning, the structure and composition of the stand, and the size to which trees are grown. Most of these features have a **gradual** influence on the stability of individual trees or stands, other than thinning where the opening up of the canopy can have a **sudden** and dramatic effect on the risk of wind damage. The theoretical basis for some of these aspects is presented in more detail in Chapter 2. In this section we focus upon the management implications.

1 Quine and White 1994

Table 1. A ranking of the vulnerability of important tree species of European forests to wind damage. Adapted from Colin et al (2009).

Vulnerable	Intermediate	Resistant
Picea abies	*Pinus nigra*	*Larix decidua*
Picea sitchensis	*Pinus nigra* ssp *laricio*	*Abies alba*
Pinus pinaster	*Pinus sylvestris*	*Cedrus atlantica*
Pseudotsuga menziesii	*Fagus sylvatica*	*Quercus robur*
Pinus contorta	*Prunus avium*	*Quercus petraea*
Populus nigra, P. trichocarpa, and hybrids	*Betula pendula*	*Tilia cordata*
Populus tremula	*Betula pubescens*	*Carpinus betulus*
Pinus radiata	*Castanea sativa*	*Fraxinus excelsior*
Eucalyptus globulus		*Acer pseudoplatanus*

Species choice

Tree species vary in characteristics such as crown size and flexibility, root anchorage and wood density and strength, which will all influence resistance to wind forces. Evergreen conifers are generally perceived to be more vulnerable to wind than broadleaves, which may also reflect the deciduous habit of the latter during the winter storm season and the tendency for conifers to be the taller trees in a forest. In addition, both spruce and pine species have been widely planted on wetter soils with shallower rooting and reduced anchorage, and such stands will therefore be highly vulnerable to strong winds. Table 1 summarises existing classifications of species vulnerability based on observational data derived from previous storm events in different parts of Europe.

However, such classifications should only be considered as a rough guide to species vulnerability since the evidence for difference between species is often confounded by soil and past management. For example, when planted on deep rooting soils supposedly vulnerable species such as Norway spruce show much better root development and stronger anchorage (see Figure 28). Similarly provenances within a species may show differing vulnerability to wind, as exemplified by lodgepole pine, where south coastal provenances have heavier crowns and a greater instability compared to material from Alaska. The most critical aspect is to ensure that a particular species is suited to the local soil and climatic conditions, before worrying about relative vulnerability to wind damage.

Cultivation, drainage and planting stock

The soils information (see above) should identify those sites in the forest where the presence of an indurated layer or soil wetness is likely to restrict tree rooting depth and anchorage. Field inspection may show that it is possible to ameliorate these conditions through appropriate cultivation, for instance by breaking an ironpan through the use of a ripper and so allowing tree roots access to freely drained soil below the pan. Similarly, carefully located drains may channel away water from wet hollows and improve soil aeration. The scale of these operations needs to be considered since experience shows that extensive drainage networks can be difficult and costly to maintain in the long-term. Small wet areas are often better left unplanted rather than becoming a pocket of early windthrow as a result of neglected drains. The potential impact of the cultivation meth-

Figure 28. Norway spruce, deep rooting on the left and shallow rooting on the right (Photos provided by Forest Research and covered by Crown copyright).

od on subsequent root architecture and long-term tree stability also needs to be considered. For example, the use of single furrow ploughing provided excellent planting sites on wet gley soils in north-west Europe, but root development tended to be mainly along the line of the furrows, making the planted forests more vulnerable to strong winds. One aim of any cultivation method should be to encourage deeper rooting and the development of symmetrical root systems. For example, the creation of spaced mounds can be used to facilitate regular root development on problematic soil types.

The choice of planting stock combined with poor planting technique can have a negative effect on root development and subsequent stability. This aspect is too often overlooked and managers should remember that root architecture of a mature tree is determined in the early years of establishment. Bare-root plants that have distorted (J-rooted) root systems or containerised plants where root spiralling has occurred can develop into mature trees with unstable root architecture. While in some species (e.g. spruces) the development of adventitious roots can compensate for poor nursery roots, in general any seedlings with misshapen roots should be discarded and not be planted. Naturally regenerated seedlings normally have a more symmetrical root system than planted trees. The planting operation can also harm the future architecture of the root system, for instance when roots are forced into a narrow spade slit and surrounded by compacted soil. The planting technique should provide a zone of cultivated and aerated soil around the planted seedling to allow ready root-soil contact.

Spacing and thinning

Although the height of the trees is the main morphological feature that affects the vulnerability of a stand to wind, the height growth of a tree or stand is essentially independent of management control, being driven by site fertility and species characteristics. By contrast, one morphological parameter of importance for stability that is influenced by management is tree diameter which is determined by the growing space available to an individual tree. The growing space is a direct result of the stocking density chosen by managers, whether as a consequence of initial planting spacing or that provided through pre-commercial or commercial thinning. The significance of diameter manipulation for the stability of a tree is because, everything else being equal, a sturdier (i.e. larger diameter) tree of a given height will generally prove able to withstand higher wind speeds than a slenderer one. Diameter is also positively correlated with rooting volume, and thus a larger diameter tree will tend to have stronger root anchorage.

A wide range of initial planting densities are used in European forestry, ranging from around 200 stems ha^{-1} for poplar plantations in lowland Europe and 1100 stems ha^{-1} for maritime pine and Douglas fir in France through 2000 to 3000 stems ha^{-1} for spruce and pines in the UK and Scandinavia and reaching 4000 to 5000 stems ha^{-1} for oak and beech in parts of central Europe. Stocking in areas of successful natural regeneration can be even higher. Wider spacing will tend to result in larger diameter and more stable individual trees but these will generally require pruning to prevent loss of timber quality. Close spacing will encourage earlier canopy closure and natural self-pruning of the valuable lower part of the stems, but the risk is that individual tree stability is reduced and the trees can be more vulnerable to strong winds immediately following thinning, especially in the more exposed regions of Western Europe. In Northern Europe an increased vulnerability to damage from snow and wind has been detected in high density stands and in stands of high density where respacing and thinning has been performed recently.

The interaction between thinning and wind damage is complex and is influenced by several factors such as the timing of thinning in relation to stand age and tree height, the pattern and intensity of thinning (i.e. the proportion of trees that are removed and their spatial distribution) and the risks due to permanent features such as climate and soil. The critical point to recognise is that all thinning will increase the potential risk of wind damage in the short-term (i.e. up to about five years) because the stand is opened up and individual trees will absorb greater wind loading before their stems and root systems have adapted to the new wind climate and the crowns have grown back into the canopy gaps. This increase in risk after thinning is the major reason why late thinning in older stands can result in major wind damage. However, in **the long-term**, a series of careful thinning operations begun early in the life of a stand can result in a lesser vulnerability to wind damage because the individual trees should become sturdier and develop better root anchorage than those in unthinned stands. One issue is that the increasing use of mechanised thinning harvesters in European forests plus feller-selection of trees for removal can result in poor patterns of thinning that do not foster the development of the stability of the stand. Better training of operators is desirable to ensure that mechanised harvesting operations do not compromise long-term tree and stand stability.

Rotation length, mixtures and stand structure

A general trend in European forests over recent decades has been an ageing of the growing stock due partly to undercutting of the increment and also to wider adoption of close-to-nature approaches to forest management. A consequence of the ageing of the growing stock has been that, on average, trees are taller and therefore more vulnerable to the risk of wind damage. Since rotation age or exploitable size is linked to trees in a stand achieving a desired target diameter, one way of compensating for recent trends is to adopt a more dynamic silviculture based on earlier and heavier thinning so that trees reach this diameter at a younger age and lesser height. The recent increase in the use of wood biomass as a feedstock for renewable heat and energy generation has created new markets for the small roundwood produced in early thinnings, which should facilitate the wider adoption of this approach.

There is conflicting evidence to support the belief that mixing a 'vulnerable' with a 'resistant' species (Table 1) will result in a more stable stand than one composed entirely of a vulnerable species. In part, this is because benefits of such mixtures are often influenced by past management and local soil conditions. In addition, the different growth dynamics of the species present in mixture will result in changes in structure over time and hence in different degrees of wind risk, for example in the progressive suppression of beech by Douglas fir. Although studies have shown different depth of rooting between species in mixed stands, there is little evidence that these patterns confer improved root architecture or stability for more vulnerable species. However, in exposed sites in Atlantic Europe where non-thinning regimes have been widely practised, the use of 'self-thinning' mixtures, where a slower growing sacrificial species is mixed with the desired species, has been found to be a means of developing more stable structures with larger tree sizes. This is because of competition within the stand whereby the desired species progressively suppresses the other component of the mixture. This provides a natural reduction in density similar to the effect of thinning but without the risks incurred by opening the canopy through the sudden removal of a proportion of the trees. Better understanding of the dynamics of species growing in mixture could provide a more general means of developing more stable stand structures in future climates.

The potential benefits of an irregular stand structure in lessening vulnerability to storm damage have been much discussed over the years, but evidence is again ambiguous because of confounding effects of management and soil and there is little indication of changing wind forces within variable stand structures. There is some evidence that dominants within mature irregular stands tend to be sturdier than those in regular ones, and therefore more resistant to a given wind speed. The thinning regimes required to develop irregular stand structures can themselves cause increased vulnerability since there may be some loss of the stabilising effect provided by crown contact in regular stands. However, irregular structures are potentially more resilient to wind damage since the presence and promotion of advance regeneration, which is an integral part of their management, should allow faster recovery of forest conditions. In addition, the presence of an understorey of advance regeneration appears to help absorb some of the wind stress on the forest and reduce the wind loading on the larger trees in the canopy layer (see Chapter 2.2).

Landscape aspects including forest edges and felling patterns

One problem with the research evidence on effects of wind damage is that most of the detailed studies have been undertaken at a stand level, but the actual impacts are critically dependent on management actions at a landscape level. For example, in forests where the risk of regular wind damage is high, design and management of forest edges should be given careful attention. Observations after serious gales shows exposed trees on the edges of forests are often able to withstand wind speeds that cause extensive damage to trees only a short distance inside the forest edge (Figure 13). This is because these edge trees show adaptive growth in response to their more extreme wind environment including improved root architecture. The aim should be to use this adaptive growth response to create a transition zone of perhaps 30–50 m on the windward edge of a forest where both tree species and spacing are varied. The result is that the wind is gradually filtered through the trees rather than being forced upwards over a solid edge and generating damaging gusts over the interior of the forest. Even in smaller woodlands, where it may not be economically practical to create such an extensive transition zone, an attempt should be made to improve permeability to the wind by fostering bushes or small trees on the outside of the wood, and by high pruning tree stems close to the edge.

Similar principles apply to the layout and design of felling areas within forest blocks. Very often felling coupes are configured with the efficiency of harvesting or landscape aesthetics as the main drivers, but the removal of a block of trees can expose a previously sheltered downwind block to a wind climate which it is unable to withstand. Clear felling an area more than 5 tree heights wide (about 1–3 ha in most managed forests in Europe) amounts to placing the downwind edge trees in full wind exposure. In windy climates or on soils with rooting restrictions, it will be prudent to locate and develop stable internal edges in advance of upwind clearfelling. Such edges may be found along streams, forest roads or on areas of deeper rooting soils. Where stable edges are difficult to find, it may be necessary to create such edges by making severance cuts at least one to two tree heights wide along the edge of a young stand so that the edge trees in the latter can progressively adapt to more exposed conditions. A traditional way of managing a forest to reduce wind impacts was to divide it into sections and to fell the sections in strips working against the prevailing wind (e.g. a strip shelterwood silvicultural system or variants thereof). Experience suggests that this can be reasonably effective on flat terrain, provided that storms do not come from an unusual wind direction, but it has proved harder to apply in hilly or mountainous terrain where the uneven topography generates less predictable wind speeds and turbulence. Another drawback of this system is that different forest owners have to cooperate over time and at a landscape level in carrying out the cuttings. This cooperation can be difficult to achieve as owners rarely have similar objectives for the management of their forests.

Given that forest managers will wish to limit the risk of wind damage, one sensible approach is to try to diversify the structure and composition of a forest so that not all blocks are equally vulnerable to a major storm. This is of particular importance in those regions where extensive afforestation occurred in the last decades of the twentieth century. The forests were often planted within a very few years so that, without management intervention, the majority of stands will reach a height where they become vulnerable to wind damage at the same time. In such situations, at a forest scale it makes sense to fell some stands in advance of rotation age so as to spread the risk. The opportunity can also be taken to introduce other desirable species with different growth rates so that the future forest becomes less uniform in age and composition.

Silvicultural strategies

Taking all the preceding sections into account suggests that there are three types of silviculture that can be adopted to reduce the risk of wind damage in European forests. Not all strategies will be feasible in all parts of the continent. Listing these in order of increasing tree size, they can be termed:

- *Atlantic forestry*. This is typified by even-aged stands managed on short rotations (< 45 years) and is associated with patch clear felling. In the maritime pine plantations of south-west France, this is based on planting at comparatively wide spacing, the development of individual tree stability through early thinning (including thinning to waste). In the Sitka spruce plantations of the British Isles, a closer spacing is used to maintain timber quality, but little or no thinning takes place and greater reliance is placed on maintaining within stand stability for as long as possible. The short rotation forestry systems used for eucalyptus in the Iberian peninsula would also fall into this category.

- *Traditional even-aged forestry*. Much of the high forest area of Europe has been managed the same way for over a century or more, with the main silvicultural systems used being patch clear felling, seed tree, and uniform, strip and group shelterwood systems. Trees are grown on rotations of at least 50 to 150 years, depending upon the species being grown and the timber products envisaged. Stands are established at close spacing, pre-commercial thinning may be carried out in the thicket stage, and this is followed by regular thinning after canopy closure to develop quality stems. In the early part of the rotation, the resistance to wind depends upon maintaining within stand stability, but the emphasis gradually changes to favour individual tree stability as a result of thinning. The vulnerability of stands managed in this way is often a function of their thinning history. In parts of Europe, respacing and/or early thinning was often delayed for marketing reasons with consequent risks when dense stands were eventually opened up. In regions where wind and wet snow can destabilise trees, a policy of heavy early thinning to favour more stable trees has been implemented, sometimes followed by a period of no thinning until the period of rapid height growth has passed.
- *Close-to-nature forestry*. This approach (also termed continuous cover forestry) is generally identified with the single and group selection systems developed in the more mountainous regions of central Europe. These systems are characterised by irregular stand structures with a range of tree sizes present in close proximity and a more open canopy structure. Thinning seeks to foster individual tree stability. In many countries of Europe, there are aspirations to increase the proportion of forests managed in this way. However, transformation of even-aged stands into irregular structures can take several decades, and there can be increased risks of windthrow if the trees are slow to respond to the changed wind loading as a result of heavier thinning. In such situations, it may be more practical to seek to develop irregular structures in the successor stand.

Management planning

An important feature of managing forests to reduce wind damage is to have good records of the local impacts of past storms and of management measures designed to limit wind effects, and to have a contingency plan in place if extreme winds are forecast (see Chapter 3.3 for a discussion of contingency plans at local to national scale). Even in forests in exposed parts of Europe, forest managers may only deal with an extreme storm once in their career and they may unwittingly adopt silvicultural practices that increase the future vulnerability of the forest. A simple plan with supporting maps that evaluates the vulnerability of the various parts of a forest to wind and outlines potential measures to be taken to limit the potential damage can be invaluable to future managers. There are a number of computer-based wind risk management tools available in different European countries, which can be used to inform the development of this plan (see discussion of Wind Risk Models in Chapter 2.3).

With modern weather forecasting, all forest managers should be able to obtain at least 24 hours notice of the advent of an extreme storm that could cause serious wind damage. One thing that can hamper the response to such an event is if all harvesting machinery and other equipment necessary for clearing roads and opening up access within the forest are themselves cut off by fallen trees. Therefore, there should be a wind risk management plan in place which identifies the infrastructure at risk from a storm and proposes remedial measures. For example, this could ensure that essential equipment is relocated to a secure and accessible centre if a major storm is forecast (see also Chapter 3.3 for more detail on such contingency planning).

Conclusion

The management of forests to reduce the impacts of storm damage is complex and there are no simple rules or guarantees of success. Disturbance from wind is a natural feature of forest dynamics and an effective silviculture will involve taking a coherent set of actions over time that can increase the resilience of a particular forest system while continuing to provide products and services of value to society.

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4.3.

Immediate crisis response

Christophe Orazio

This chapter describes best practices for crisis management as identified in the report on "Destructive Storms in European Forests: Past and Forthcoming Impacts" and as discussed in the stakeholder panels having contributed to the report[1]. Many of the procedures described below are already anticipated but not necessarily implemented in most of the countries at risk and need to be supported by all policy makers. Only the direct immediate response and the recovery phase following a storm are described in this chapter with the assumption that the preparation phase has already been implemented (e.g. staff training, negotiation on committee composition and derogations, contingency planning, etc.: see Chapter 4.1 for further details on risk management and Chapter 3.2 for the longer-term response requirements).

Alert phase

The map of critical wind speeds for European forests (Figure 29) shows the areas of highest vulnerability (lowest critical wind speeds). The vulnerability of the forest together with the local wind climate defines the risk to a forest area (Figure 27). In areas with higher levels of risk a contingency plan defining procedures, stakeholders and key contacts involved in crisis management should be prepared prior to a storm event. This plan should anticipate at least three levels of crisis management: regional, national and trans-boundary. It would describe all the bodies involved in the crisis management, their methods of coordination, their roles, and the derogation tools prepared. It also needs to be checked on a yearly basis. All the items discussed in this chapter that can be part of the contingency plan are marked with a "***p***".

Planning for forest storm damage provides clear benefits to member states in terms of the efficiency and safety of post-storm actions. A central point for sharing good practices could be established at a European level.

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1 Gardiner et al. 2010, available at http://ec.europa.eu/environment/forests/fprotection.htm

p: Item that can be addressed in a contingency plan prior to a storm

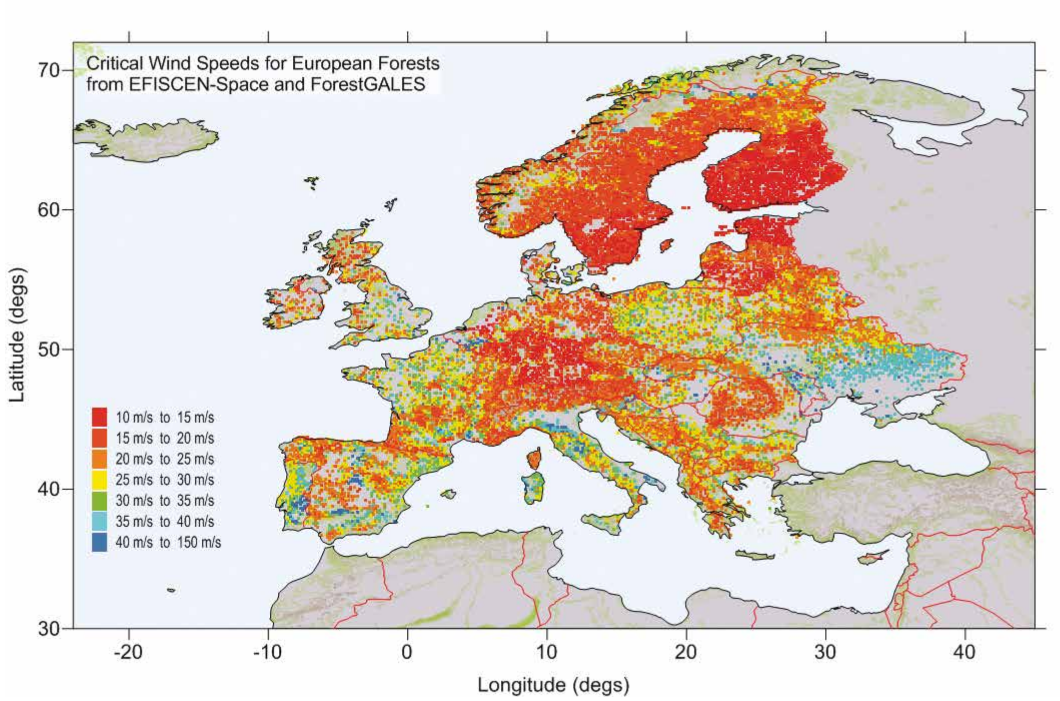

Figure 29. Calculated critical wind speeds for European forests: note only areas with >10% forest cover shown.

When a storm is announced, the main precautionary measures to take are:

- Set up a pre-crisis group [P], gathering relevant experts for the area likely to be affected and the accessibility needed to coordinate possible post storm actions.
- Anticipate low accessibility in more affected areas by positioning teams in safe and remote key locations [P] so that they are able to open roads and to carry out damage inventories as soon as the storm ends.
- To anticipate communications failures distribute appropriate alternative communication tools [P].
- Request specific satellite pictures or other data relevant to the possible crisis management.
- Inform and alert public and forest companies so that they don't go into the forest [P].

Initial response

In coordination with the safety services and the assessment of other people affected, the first hours after the storm must be dedicated to defining the level of crisis faced. Classically a crisis is defined when the damage faced exceeds the capacity of management to deal with it. In forestry, we can roughly consider that a crisis is reached when more timber is damaged than harvested in a single year in a certain region or in the country (see also Chapter 3.2). This assessment can be affected by other circumstances such as the timing of the storm. For example, a storm occurring early in the harvesting season might have a reduced impact because field crews can still be easily moved. This primary assessment [P] must be done using all possible sources of immediately available data such as remote sensing, airplane surveys and existing professional networks, in order to provide basic information on affected areas.

European countries should take advantage of a harmonized monitoring system for forest damage (primary, secondary, biotic and abiotic) and an organized trans-boundary (regional or national) alert and crisis management system. This would allow a more accurate assessment of the damage level and the appropriate local, regional, national and European response.

The damage assessment method must be described in the contingency plan, based on existing resources.

After the initial rapid assessment of damage, the appropriate measures in the most affected areas are:

- Restriction of public access to forests, [P]
- Clearing and restoration of infrastructure and services such as electricity, telephone and public and forest roads, [P]
- Psychological support, including telephone call centres for affected people, leaflets and standardised messages for mass media diffusion [P]
- Instruction of teams for infrastructure restoration including clearing roads. [P]

Recovery phase

Once the initial emergency phase is over, it is important to get a more precise view of the actual damage in order to plan for the salvage of the wood and restocking of the area. A combination of field inventory and remote sensing approaches are needed to establish the area, the volume, the species, the quality and the percentage of trees damaged in stands. The time wood can stay in the forest without declining in quality depends on the species, the time of the year, and if the trees still have root contact. Beech trees are susceptible to blue stain fungi and should be salvaged within a few weeks, windblown pines with living roots can stay in the forest at least for a year without losing much quality and Sitka spruce has been found to maintain its quality for at least 18 months. Another consideration in planning salvaging operations is helping to reduce the risk of secondary damage, for example from fire or insect outbreaks.

Relevant information on the best storage options, wood depreciation rate, and potential threats associated with local species and climatic conditions should be available from the preparation phase and as part of the contingency planning [P].

Governments can decide to help with salvage operations in several ways. This can include:

- Operational measures such as a central point for the offering and requesting of harvesting capacity

- Financial measures such as grants for harvesting and transport companies, investment for new storage and transport infrastructure, etc.
- Technical assistance in setting up and managing the logistics of wood storage and mobilisation of wood usage.
- Political measures such as temporary derogation of transportation regulations, funds for restoration of degraded roads and exceptional harbour and railway investment, temporary rules for the employment or subcontracting of foreigners, etc..

As most countries will take similar temporary measures (issuing of grants, derogation, requests for calamity funds, etc.) EU regulations should define a set of rules that can be implemented immediately after a storm without the need for negotiation. This could be triggered by a certain level of damage in order to accelerate the process of mobilising the harvesting, transport and use of wood from the affected area

The level and the duration of these transitional measures will depend on local industrial capacities and on the strategic choice made
(i) to store the damaged wood for regional processing or,
(ii) to increase the wood trade by selling to new buyers not normally active or familiar with the affected area.

The first option requires knowledge on storage procedures and established storage infrastructure or the funds to quickly establish the storage platforms. The second option will put emphasis on the infrastructures for distribution and transport and will require a good and up-to-date knowledge of the timber market and potential buyers. Usually it is some sort of intermediate strategy that is adopted, trying to store as much as possible wood that can be utilized by local industry and transporting damaged timber that cannot be processed in the area to other regions or countries. If a significant amount of damaged timber cannot be processed locally, market disruptions at regional, national and even European level may occur (see Chapter 3.3).

There is a need for a transregional/transnational approach to anticipate market disruption and to coordinate policies following storm damage.

When the market and sector disruption is extremely high there is a need to limit the cascading effects that follow. As an example, to avoid price collapse it is necessary to develop methods for salvaging the blown timber and ensure a financial return to the forest owners. Certain marketing measures [P] that can help include:
(i) collective agreements between purchasers and sellers on minimum prices,
(ii) grants for round wood transportation or additional logging costs of wind damaged timber,
(iii) financial guarantees for roundwood buyers,
(iv) limiting the import of timber into the region and the harvesting of non damaged stands,

(v) promoting the use of wood products,
(vi) initiating local and regional fund-raising to support the sector.

Examples of incentive measures [P] to limit the harvesting of non-damaged stands and to support the revenues of forest owners or enterprises directly affected by the storm include direct support of both damaged and undamaged forests by a reduction of capital, wealth, income or value added taxes.

In addition to these measures, risk mitigation measures should be considered to avoid additional outbreaks by bark beetles or fire. This can be done by recommending or imposing bark removal or chemical treatment of log piles and increasing the fire fighting capacity and fire patrols in the years following the storm.

As ecosystems are always affected by such events, certain environmental services might be disrupted including soil erosion protection, water quality and biodiversity. They can be helped to recover by defining priority areas for harvesting and restoration of forest cover. Conversely, game numbers might increase as a consequence of lowered hunting pressure (due to difficulty of access) and an increase in food availability and quiet areas. However, game damage to trees should be anticipated before restoration starts by using appropriate fencing or encouraging an increase in hunting. Another risk, which is related to rot diseases and the increased movement of timber over long distances, is the spread of diseases to soils and stands both within and outside the affected forests. Prevention methods must be advertised or made mandatory.

In most of cases, during the months following a storm, forest sector activity will be unusually high and operators should be allowed to benefit from temporary and accelerated depreciation of their logging equipment, and temporary derogation of working hours legislation to extract wood as fast as possible, especially in countries with climatic restrictions on harvesting activities in part of the year.

When considering the ability to restore the forest it is important to determine whether the stand regeneration capacity and seedling production is still functional [P] and that mature seed trees, seed orchards and nurseries were not critically affected by the storm. In addition, if wood prices fall too much forest owners might be reluctant to invest again in forestry. Incentives to restore and regenerate forests at no cost to the owners will limit the chance of deforestation or forest abandonment. When restoration of forests is granted directly to the land owner, monitoring of regenerated areas is recommended to be sure that forests will be managed over the long-term and the wood resource properly re-established. The best options have to be selected to reduce the future susceptibility of the restored forest to storms (Chapter 4.2) or to mitigate the impact of storms on the forest sector (Chapter 4.1), taking into consideration forest owners' behaviour to risk (Chapter 4.4).

The final requirement after the crisis management period is a retrospective analysis on what happened. From this analysis, improvement in the procedures, in the data collection, and in the previous risk management options selected will be of benefit to the whole sector. Gaps in knowledge can be identified, and required research programmes can be initiated. In this way, the main procedure and contingency plan for the crisis management of future storms can be significantly improved. This process forms a key component of the overall risk management of forests, which is described in further detail in Chapter 4.1.

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4.4.

Risk management and risk perception – understanding the social dimensions in responding to the threat of storm damage

Mariella Marzano, Kristina Blennow and Chris Quine

Risk management and decision making

Although risk is sometimes considered only to relate to the probability of occurrence of a hazard, it is often regarded as a function of both probability and consequence. In the case of storm effects on forests the probability is a function of the wind climate and the sensitivity of the forest (see Chapter 2). The most obvious (direct) consequence is change to the structure of the forests and stature of individual trees through windthrow (overturning) and wind breakage of trees. However, from a human perspective, there are a range of other aspects of value. These include the risk of personal injury when the trees fall and during salvage harvest operations, the loss of economic value represented by the trees, and the loss of other attributes and values such as habitat for wildlife, sources of food, as a cherished part of a landscape, and as shelter for livestock (see Chapter 3).

Risk assessment tools can provide estimates on the probability of storm damage to inform decision-making but how risk is perceived and acted upon will depend on a range of different social, psychological (e.g. cognitive), political and economic factors.

How risk is perceived by an individual can be influenced by the values associated with the object at risk, past experiences and familiarity with the hazard, social relationships and networks, 'voluntariness' or perceived control (over the hazard) and trust in institutions and experts.

Risk management is the process whereby decisions are made to accept an assessed risk, and/or the implementation of actions to reduce the consequences or probability of occurrence (see chapter 4.1).The choice of whether to respond to the risk and which response is appropriate is made by a decision maker. Risk management decisions may be based on subjective judgement or quantitative assessments of risk. Tools for quantitative assessment of risk have been developed to support the decision maker (see Chapters 2.2 and 2.3). A risk assessment tool usually provides estimates of the probability of occurrence of a hazardous event such as a wind storm. Under the assumption that the value of all consequences can be monetized, some risk assessment tools also include estimates of the monetary value of what is at risk (how other kinds of values are dealt with are addressed in Chapter 3.4). However, it is also important to recognise a host of other factors that influence decisions and perceptions of risk. Given an assessment of risk, three broad decision strategies can be adopted; acceptance of level of risk and subsequent losses, attempts to spread loss (e.g. through insurance), and efforts to reduce loss. In the case of storm damage, loss reduction can be achieved by risk avoidance (e.g. land use decisions avoiding the establishment or ownership of forests on wind exposed sites) or by risk reduction in which the sensitivity of the forest is modified, for example by silvicultural practices (see chapter 4.2).

However, there have been remarkably few studies examining how decision-makers perceive and respond to the potential risk of storm damage to their forests. Among the very few studies available in relation to forestry, most have been made with private owners and managers in Sweden. However, we can also learn from the extensive research and discussion that has evolved around risk perception and communication with individuals and communities with a particular emphasis on augmenting available evidence on the social dimensions of storm damage with other natural hazards such as flooding.

Perceptions of risk

Risk perception is an important determinant of behaviour, and so it is necessary to understand how people may weigh up the risk of storm damage in their forest management planning. Decision-makers are often characterised as risk-averse, risk-neutral or risk-taking with reference to their sensitivity to risk. Decision-makers (who could include forest owners, managers, government officials etc.) can be influenced by the level of calculated risk (assuming it can be accurately estimated and the degree of uncertainty specified), their attitude to risk (often shaped by past experience of the damaging agent), and the context provided by a host of other factors (including scope of responsibility, objectives of management, method of valuation losses, scale of enterprise, and risk to human life). However, it is difficult to translate scientific risk estimates and calculations of probability into how risk is understood by people.

There is a wealth of literature that suggests decision-making about risk in the context of uncertainty is governed by social, cultural, political and economic factors. Risk perception is not fixed but dynamic and open to change over time. It is also personal to an individual with hazards and risk meaning different things to different people. Thus, how an individual evaluates what is or is not risky or the seriousness of a risk depends on a range of factors and background knowledge. These include social relationships and networks, trust in institutions and experts, experience, voluntariness or perceived control and familiarity with the hazard. The role of these factors in risk perception has been comprehensively deliberated in the literature and provides insights that are a useful starting point for understanding how individuals and communities may think about storm damage in forests.

Risk communication plays a part in risk perception, but is not simply about information provision or availability. What is important to highlight here is that risk messages may be judged not only by what they say but also whether the source of the information is trusted. Trust is a crucial component of risk perception, particularly where people do not possess detailed knowledge of the risk and thus rely on experts and other sources. For example, many private forest owners in Sweden trusted forestry consultants to provide expert advice on risk management augmented by a general acceptance and trust in the Swedish forestry culture. However, less than half of 390 private owners who took part in a survey in 2004 had actually been advised on wind damage risk. Consultancies were found to be largely providing the same management advice, based on forestry traditions of collective or national risk assessment, irrespective of local conditions, and individual owners were not invited to bring their own perspectives to bear on the issue.

Recent psychological studies of risk have highlighted that instinct or emotional responses play an important role in risk perception. Emotion or experiential-based responses involves an individual's intuitive and automatic response to a stimulus experienced as a good feeling or bad. This reaction often informs information processing, decision-making and evaluation of an action. In other words, people may base their judgement not only on what they *think* about a hazard and actions to mitigate against it but also how they *feel* about it.

How people think and feel about a hazard is also influenced by their level of voluntariness; that is the extent to which they have control over the hazard itself or exposure to the hazard. Hazards that are seen as involuntary, uncontrollable or that have delayed effects can induce fear and dread and increase the perceived risk. Conversely, familiarity with a particular hazard has been said to reduce perceptions of risk. Other strategies to deal with the inherent uncertainty associated with a natural hazard involve risk denial such as thinking "it won't happen to me", or taking the position that a hazard event is unlikely to occur more than once. A study of non-industrial private owners in Sweden found that they were less likely to manage forests to mitigate against storm damage as it is seen as a 'natural hazard' or an 'Act of God' and therefore less avoidable than a risk that depends on forest management. This may explain why only about one third of the forest owners have taken action to reduce the risk of wind damage even though individuals believe the risk of wind damage to be high and likely to get worse due to climate change. Similarly, another study on residents' perceptions of flood risk in Germany found that people were less supportive of mitigation measures that required a personal level of involvement and responsibility.

Evidence suggests that social networks influence whether and how individuals seek risk-related information and also how they process it. Social networks can include a multitude of relationships including family, friends, neighbours, social media, workplace, associations and community. Perceived impacts of natural hazards can be identified at an individual but also a community level, particularly where forests play a key economic or social role contributing to jobs, local identity and quality of life. A study on community attitudes and reactions towards a public health hazard reveals that at the community level it is possible for one overall perception of risk to occur through which individual or group risk perceptions are filtered. Thus risk perception often emerges from social interaction. It is through mechanisms such as this that social amplification of risk can occur. The perceived risk thus becomes magnified compared to the assessed risk and may trigger significant responses.

Risk communication is a complex process that is not simply about information provision. How people receive and act upon information can depend on many social factors such as whether the source of the information is trusted.

More research is needed on the social dimensions influencing attitudes towards risk and challenges that may affect decision-making.

It has been noted that owners and managers have very different motivations and goals regarding their forests with income and monetary profit/loss not necessarily predominant. Forests engender multiple values and benefits. For example, many non-industrial private owners in southern Sweden do not actively manage for wind damage risk despite wind damage being identified as one of the most significant financial risks to their forests. This meant only about 40% of forest owners were insured against loss of income from storm damage when storm 'Gudrun' hit in January 2005. Although this seems surprising, it is perhaps less so given the fact that on average a Swedish individual owning a forest only earns 12 % of their household income from forestry and they usually have many other reasons for owning a forest such as the lifestyle it brings or recreation. An insurance policy would not help restore these other values after a wind damage event.

Risk research shows that the extent of storm damage is dependent on how stable the forest is and this depends on decisions around how the forest is managed (see Chapter 4.2). Management decisions related to storm damage in forestry is difficult in the face of uncertainty, and depends on the goals for the forest, the level of risk that is acknowledged and/or accepted, as well as the resources available for such management.

Risk perception has also been described as political in the sense that individuals, groups, organisations or institutions often make decisions about risk for other people. For example the low probability of extensive wind damage in Sweden coupled with a national policy decision of promoting production-oriented forestry which leads to more and larger trees, rendered forests, particularly in the small-scale private sector, more vulnerable to the storm of 2005.

Therfore, experiences with past storm impacts may serve as an important element in influencing risk management and choice of response. There is evidence to suggest that where natural hazards happen infrequently, experience is often limited and may thus be an inadequate source of information on which to base any mitigation activities. Findings suggest that the impact of rarer storms on forest wind damage could be exacerbated because memory of how to manage for these storms decreases over time, although there is some disagreement over the impact of repeated experience of a hazard. In relation to, for example, frequent flooding, some evidence suggests that people can become so used to a hazard that mitigation is not considered and the risk simply accepted, whereas other research suggests residents were more receptive to adaptive measures when convinced that flooding in the future was inevitable.

Future research

Much research is needed in the field of forestry around understanding perceptions of uncertainty and risk in the context of storms. A study on attitudes and behaviour relating to mitigating the risk of wildfire in residential areas provide a conceptual framework to allow prediction of a person's intention to carry out specific activities. It includes (i) attitudes towards mitigating activities, (ii) strong persuasive influences of social networks, and (iii) perceived barriers to carrying out the activity. Some work has already been started in developing forest manager 'types', their likely reactions to potential storm risks and sensitivity to estimates. As well as assessing what risk management is currently taking place, future work might need to focus on the level to which varying social factors such as experience and access to social networks influence perceptions of risk, decision-making processes and action (or inaction). It would also be important to place decision-making within a wider local, regional and national context to identify key socio-economic, political and environmental drivers that may influence or constrain management choices. For example, are the differences between national forestry objectives and the private forestry sector in Sweden observable in other countries? Are some risks considered more important than others in different contexts? Additionally, examining the linkages between risk communication and behaviour change will usefully inform efforts at providing information and advice on managing for storm damage risk.

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5.

Future Prospects

5.1. Climate change and storm damage risk in European forests

Marcus Lindner and Markku Rummukainen

Climate change

A wealth of observations document the fact that global climate change is already happening. This is evident from global and regional warming patterns, changes in the Arctic sea ice cover, glaciers and snow cover, and sea level rise, amongst other indicators. Studies that address the underlying reasons for the observed changes point to a decisive human influence. While expectations of further warming and consequently changes in many other climate elements are well-founded, significant uncertainty remains as to the overall magnitude of the changes, their regional characteristics and not least the possible changes in small-scale phenomena such as storms. A fundamental source of uncertainty comes from the uncertain anthropogenic emissions over the decades to come. They depend strongly on global economic development and other anthropogenic factors that are very difficult to foresee. In addition, the efficiency of the global carbon cycle may come to change under warming and thus change the amount of the emissions that accumulate in the atmosphere. The next step, projecting climate change due to such forcing, is in turn subject to our incomplete understanding of all climate processes, which implies climate model uncertainties. Like other models, the global climate models which are used to model the earth's climate are simplifications of the real world. These global models are typically of relatively coarse resolution (of the order of 100–200 km) and thus not sufficient for the regional-to-local scale impact assessment required to investigate climate change impacts on forests. Rather, downscaling methods such as regional climate models and statistical methods are used to transform the coarse outputs of the global models to climate projections at medium (10–50 km) or high (forest stand) resolution, with their own inaccuracies and systematic biases. Finally, internal climate system variability is not deterministically predictable and natural climate forcing is inherently uncertain. Climate projections are thus fundamentally different from short-term weather forecasts. Although climate models do simulate the evolution of the climate system over time, their results should be seen as scenarios of the statistical properties of the climate; mean values, typical variability and the likelihood and characteristics of extremes.

Changes in temperature and precipitation regimes

The body of climate projections for Europe show statistically significant warming of the European continent in the future. This warming is most pronounced in the north-east during winter and in the south during summer. The change signals for precipitation are more variable but show a general increase in the north and a decrease in the south. The borderline between the distinct increases and the distinct decreases is a fairly broad zone (of the order of 500 km) that migrates back and forth from a northerly position in summer to a southerly position in winter. This means that summers tend to get drier in most parts of Europe, whereas winter precipitation is expected to increase over considerable parts of Europe and stay relatively unchanged in the south. These general patterns are robust across many scenarios, but the magnitudes of the changes vary with the emission scenario and to some degree also between different climate models.

To provide some quantitative examples that also reflect the typical overall characteristics of regional scenario results, Figure 30 presents a set of projected changes in different European regions, based on a range of regional climate models driven by global climate models that were all run in the ENSEMBLES project and built on the A1B scenario of the IPCC[1].

Climate projections over the 21st century vary considerably between models and also between emission scenarios. In general, on the global scale, model uncertainty dominates the forcing (emission) uncertainty up to around 2050, after which forcing uncertainty starts to become more important. However, at the regional scale model uncertainty dominates forcing uncertainty for longer into the century because it takes longer for the forced change to exceed the existing natural variability (natural variability is larger in many regions compared to the global mean). Therefore, it is reasonable to compare alternative climate projections from different global and regional models for the early part of the 21st century in order to gauge uncertainty, rather than considering single models with multiple emission scenarios.

The projections for seasonal average temperature increase in Europe (here: 2071–2100 compared to 1961–1990) usually show a range between models of about 2°C. It should, nevertheless, be noted that the future emissions are uncertain and the projected climate towards the end of the 21st century could exceed the range depicted in Figure 30, towards either lower or higher values.

For forest growth and disturbance risks, climate variability and extreme events are often more important than changes in average conditions. Climate models project various changes in frequency, intensity, and duration of extreme events, including more hot days, more severe heat waves, more heavy precipitation events, and fewer cold days over the course of the 21st century.

Changes in wind extremes

There is generally high uncertainty attached to wind climate projections and possible changes in storminess. There are several reasons for this including the fact that the large variation in extreme events like storms implies that we do not fully know the baseline of recent past and present conditions, against which projections are compared. Furthermore, given the considerable spatial variability in the wind climate, the available observations of the maximum wind speed field preclude interpolation of point observations

1 Current emissions are running slightly above the original IPCC A1B scenario

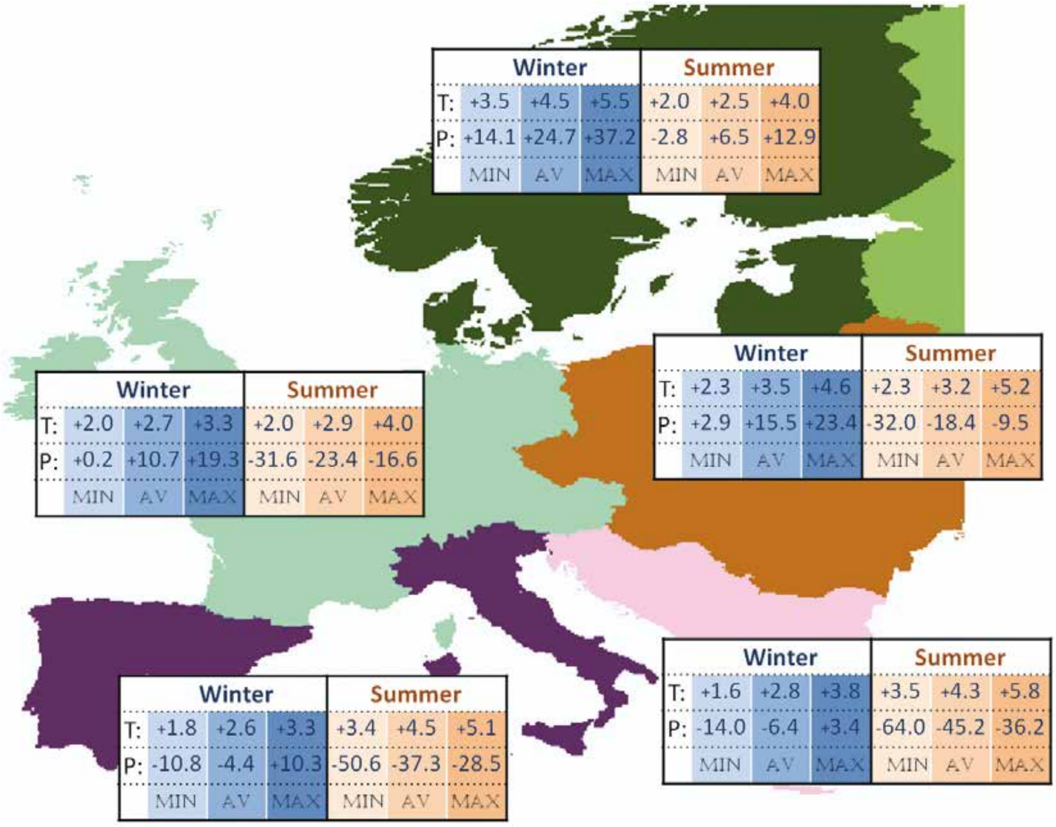

Figure 30. Changes in mean seasonal temperature (T; degrees Celsius and seasonal precipitation sum (P, % change) projected for the years 2071–2100 compared to 1961–1990. Grid level climate change projections have been averaged for country groups in the North, Central-West, Central-East, South-West, and South-East of Europe. Average values (AV) have been calculated from six global/regional climate model combinations which were all driven by the A1B SRES emission scenario. To document the model-based uncertainty of the climate projections, the projections showing the lowest (MIN) and highest (MAX) values in temperature and precipitation are indicated next to the averages.

to more spatially extensive grids. Finally, extreme wind speeds often occur at a very local level and thus cannot be properly simulated in global climate models. Performance of regional climate models in estimating wind speed distributions is also highly variable and few models include a wind gust parameterization to better represent high wind speeds.

The frequency of extra-tropical cyclone activity (i.e., mid-latitude storms, such as those affecting Europe especially in winter) undergoes natural decadal variability and possible trends in storm activity are difficult to detect in the observations so far. However, some studies suggest that storm activity over the British Isles, wind speed in the Mediterranean region during summer, and over the Baltic Sea[2] may increase due to climate change. Storm tracks may also shift further north, with the consequent possibility of increased and decreased risk of damage in different regions.

2 Nikulin et al. 2011. Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations. Tellus A 63, 41–55.

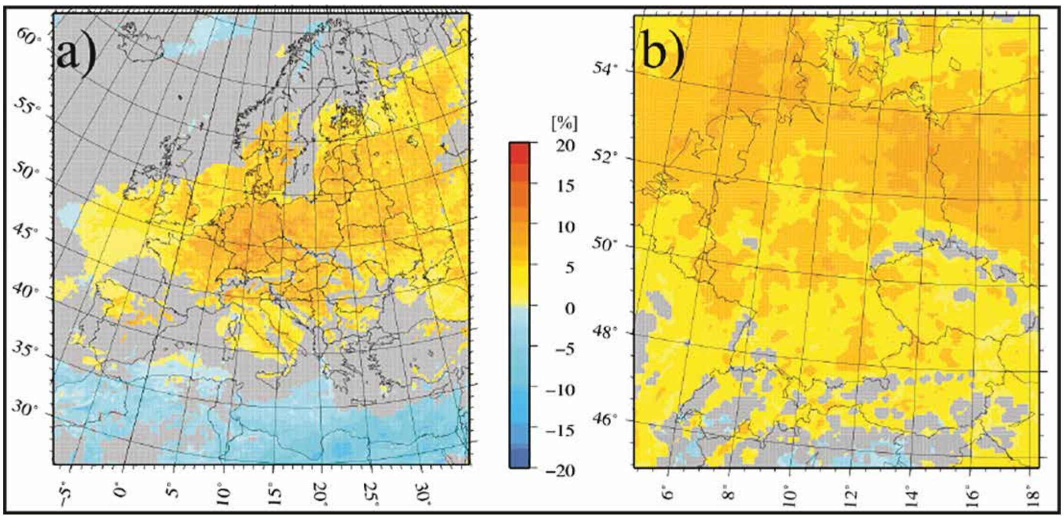

Figure 31. Relative change (in %; 2070–2099 versus 1970–1999) of a measure of extreme wind speed, simulated with two regional climate models nested into the ECHAM5 climate model with mid-range unmitigated emissions: a) all of Europe (based on one of the models) and b) Central Europe (based on the other model). Colours indicate significant changes (95th percentile confidence level). Non-significant changes are in grey. Source: Fink et al. 2009.

In addition to the number of storms and their spatial occurrence, it is important to consider possible changes in storm intensity. For example, measured wind gust speeds have increased strongly in Switzerland since the beginning of records in 1933. Again, there is uncertainty in the predictions, but some results indicate increases. A specific index of storm intensity based on the exceedance of local thresholds of daily maximum wind speed shows positive trends in the severity of storms for both the period 1960-2000 and under projected climate change conditions. Additionally, an increase in the spatial extent of storms was predicted, amounting to about 10 % increase as compared to the present day climate. The main reasons for the increase in severity are the occurrence of higher wind speeds, and larger areas affected by storms. These larger areas result from longer tracks combined with a common broadening along the path. Eastern Central Europe may therefore be exposed to more intense storms by the end of the 21st century. Higher storm intensity implies also a reduction in the return period of damaging storms. For example in the British Isles/North Sea/Western Europe region (45°-60° N; 10°W-30°E), high intensity storms with an average return period of 20 years under the 20th century climate could become 10-year events by 2030–2040, and the return period could further decrease to around 5 years by 2100. Another recent analysis for Northern Europe, however, found a small increase in sustained extreme wind speed with long reoccurrence intervals, but for most of the 21st century this did not exceed the envelope of historical variability. Figure 31 shows projected changes in a measure of wind extremes (the 98th percentile of the daily maximum surface wind speed) in autumn and winter, using outputs of the ECHAM5 global climate model, the results of which are close to a larger set of global climate model ensemble means for changes of storm track activity.

Possible key changes to storms

- Spatial extent of individual storms is expected to change (broader path and/or longer extensions eastwards)
- Changes in extreme wind speeds (reduced return period for strong winds)
- The areas most affected by storms may change because of shifts in storm tracks

Besides wind speed, temperature and precipitation are critical factors influencing the risk of storm damage. Cold-season warming extends the duration of unfrozen soil conditions, which will reduce the root anchorage of trees in regions where soil is commonly frozen during the winter. For example, it has been estimated that the period when the ground is frozen will decrease by 1–2 months in Finland. However, counteracting effects can also occur depending on other concurrent changes. For example, when the thickness of the snowpack is reduced the insulation provided by the snow reduces and the presence and depth of the ground frost may increase. But in general, periods with wet unfrozen soils are going to be much longer across Northern and Eastern Europe. Winter precipitation that is expected to increase, in particular in mid and northern latitudes, is likely to increase periods with excessive soil moisture. As trees on water-saturated soils are much more vulnerable to wind damage this will further aggravate damage risk under climate change.

Important possible changes in climate for tree stability

- Increase in extreme wind speeds with a consequent higher probability of damage in affected areas.
- Longer periods of unfrozen soils in for example Fennoscandia leading to reduced root anchorage during the winter.
- Increased winter precipitation leading to more saturated soils and reduced root anchorage in many parts of Europe.

Forest vulnerability to climate change and future storm damage risk

Forest productivity is expected to respond differently in different areas across Europe to climate change. Whereas climate warming will prolong growing seasons and stimulate forest productivity at least over the short to medium term in Northern and parts of Central Europe, enhanced water limitations are likely to negatively affect forest productivity in Eastern and Southern Europe. Increasing carbon dioxide levels can in turn affect growth, and water-use efficiency and soil processes can also change with warming. Changes to extreme events are likely to increase damage caused by forest disturbances including drought, forest fires and insect outbreaks. Although there are a number of natural mechanisms for inherent adaptive capacity that will support adjustment of forests to climate change, the projected rate of environmental change threatens to exceed this natural capacity, especially in the Mediterranean region. Planned measures therefore may be needed to complement the natural adaptation of forest ecosystems.

In conclusion, climate change induced changes in extreme winds, storm frequency and intensity are more uncertain than temperature projections. Nevertheless, there are several factors that could increase the risks to forests and forestry in the near, mid- and long-term future:

(i) An increase in the intensity of strong storms according to several models (but not all models agree).

(ii) Changes to storm tracks could change the areas most affected by storms and increase damage in areas previously relatively unaffected. Some regions of Northern and Eastern Europe in particular could experience increased storm occurrence for this reason alone.

(iii) Higher temperatures and increasing precipitation during the winter increases the susceptibility of forest stands to storm damage because of weaker anchorage of roots in unfrozen and water saturated soils. Higher temperatures may also lead to increased pathogen activity which can weaken tree root systems.

(iv) Increasing growing stocks and ageing forests will further aggravate the vulnerability to storm damage across Europe, unless management is adapted to these changing conditions.

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5.2.

Future of European forestry

Kit Prins and Mart-Jan Schelhaas

Introduction

Foresters must deal with uncertainty and risk regarding storms and many other economic, social, institutional and ecological factors. These need to be taken into account in their management decisions. These uncertainties change over time, but can be reduced by analysis of trends and options. The outlook for European forestry, and the main challenges for forest sector policy makers, have been extensively analysed and there is broad consensus about the key questions, if not about the answers.

This chapter is based on the latest European forest sector outlook study (EFSOS II) published in September 2011, prepared for the United Nations Economic Commission for Europe and FAO, the latest in a 60 year series of official studies of the long term outlook for the forest sector in Europe. It covers all aspects from silviculture to markets and recycling, in the context of sustainable forest management. The study's priority audience is policy makers, but it is also intended to act as background and input to dialogue about more specialised issues, such as those surrounding storm damage. This chapter presents the main conclusions of EFSOS, as background to the discussion of how European foresters can address the challenge of storm damage.

This chapter concentrates on a few strategic directions emerging from EFSOS II. For reasons of space regional differences cannot be presented, although they are very significant. Nor does it speculate about the period beyond 2030, as the uncertainties on the demand side become too large. The underlying assumptions are for a stable population in Europe, slow economic growth and moderate climate change; on average leading to increment which is 4.5% higher in 2030 than in 2010. Natural disturbances are not included in the model framework. "Europe", for EFSOS II, refers to all of Europe, including Turkey and Eastern Europe, but not Russia. EFSOS II is based on the analysis of a reference scenario and four policy scenarios. The reference scenario describes the possible outlook if long term trends and policies remain as they have been in the past. The policy scenarios address the consequences of strategic policy choices by the European forest sector. The scenarios are constructed by combining the projections of several complementary models and methods.

Reference scenario

In the EFSOS II reference scenario, demand for wood will continue to grow, by an average of nearly 1% per year (Figure 32). Demand for forest products will grow rather slower than in the past, but demand for wood energy is expected to increase much faster. In

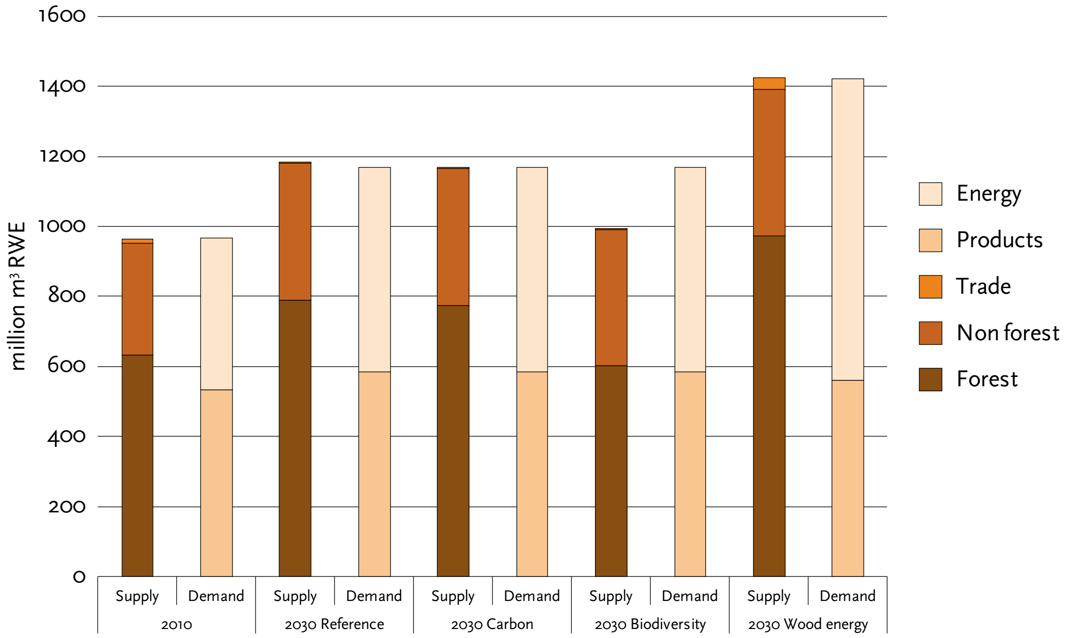

Figure 32. Supply/demand balance in quantified EFSOS II scenarios.

2030, even without special measures to promote wood energy, energy uses are expected to account for 50% of wood demand, compared to 45% in 2010.

The European forest resource is expected to continue to expand, by 0.6 million ha per year, due to natural afforestation of former agricultural land and plantation programmes in some countries. Forest managed for biodiversity conservation is expected to expand more than forest available for wood supply.

To meet the increased demand, the wood supply will also increase, by more than 22% in 20 years. Stemwood removals will rise, although fellings will remain well below increment (in 2030, 786 million m^3 of fellings, compared to 992 million m^3 of net annual increment). However other components of wood supply will increase faster than stemwood removals. Supply of harvest residues and stumps will nearly triple between 2010 and 2030, and landscape care wood (wood from urban trees, roadside trees, horticulture etc.) by 28%, while post consumer wood, such as used pallets or demolition wood, will increase by 57%. In this way, it will be possible to increase the wood supply from a practically unchanged area of forest available for wood supply. .

In the reference scenario, Europe's trade position as a major net exporter of products and a minor net importer of wood will be maintained (Figure 33). Because of rising demand and limited supply, in Europe and elsewhere, as well as rising energy prices, prices for both wood and forest products are expected to show steady long term growth, which should have a positive impact on the revenue of forest owners[1],:

1 Three countries showed negative net revenue from forests over the past 20 years (SoEF 2011).

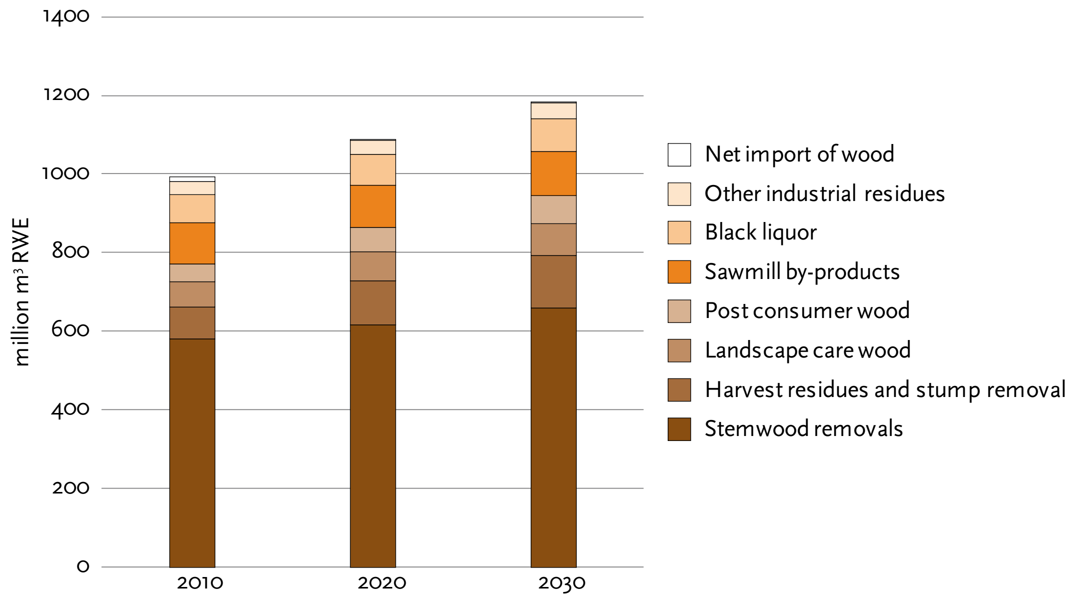

Figure 33. Components of wood supply for Europe, EFSOS II reference scenario.

According to the method developed for EFSOS II, the reference scenario is sustainable for the five criteria assessed: forest resource and global carbon stocks, health and vitality, productive functions, biodiversity and socio-economic functions. The main concern is for biodiversity due to the increasing harvest pressure.

Changes in European wood supply and demand: EFSOS II reference scenario

- Demand for wood will continue to increase especially wood for energy production
- The European forest resource will also continue to increase
- Increases in removals of stemwood, other forest sources, landscape care wood and post-consumer wood will be able to supply the European wood market until at least 2030

Policy challenges and policy scenarios

EFSOS II analyses four policy challenges by constructing scenarios built on specific policy choices.

Climate change mitigation

For climate change mitigation, the challenge is to find the best combination of carbon **sequestration** in forests, carbon **storage** in forests and harvested wood products, and **substitution** of non-renewable materials and energy by renewable wood-based products and fuels. According to EFSOS II, the best strategy is to combine forest management focused on carbon accumulation in the forest (longer rotations and a greater share of thinnings) with a steady flow of wood for products and energy. In the long term, however, the sequestration capacity limit of the forest will be reached, and the only potential for further mitigation will be regular harvesting, to store the carbon in harvested wood products or to avoid emissions from non-renewable materials and energy sources.

Promoting renewable energies

The second challenge is to ensure that wood plays its role in achieving the broad social and environmental goal of increasing the share of renewable energy, for instance by reaching the EU targets in this field by 2020. If wood is to play its part in reaching these targets, and without expanding the forest area, wood supply would have to be mobilised strongly, increasing by nearly 50% in twenty years. This estimate is based on rather favourable assumptions about energy efficiency and increases for other renewable energies. However, the mobilisation of such large volumes would have significant environmental, financial and institutional costs. To achieve this level of highly intensive silviculture and harvesting, strong political will would be necessary to modify many framework conditions for wood supply. The very high levels of extraction of residues and stumps would negatively affect nutrient flows, soil carbon and thus water holding capacity and biodiversity. Forests would also be less attractive for recreation. It would also be necessary to establish biomass plantations, perhaps using short rotation coppice, over large areas, and to import wood energy from other regions. It would be critically important that all energy from wood is produced efficiently, for instance in combined heat and power installations, and cleanly, with filters to prevent diffusion of fine particles, which are harmful to human health.

Protecting biodiversity

The third challenge is to halt and reverse the loss of biodiversity in Europe, and notably its forests. There has been considerable progress in this direction over the last 10-20 years (SoEF 2011). If governments, with the support of society, wish to give priority to forest biodiversity, they should do this in the context of a consistent approach to all parts of the forest sector. EFSOS II examined the possible consequences of managing more land for biodiversity and changing forest management to favour biodiversity. The supply of wood from the European forest would be 12% less than in the Reference scenario, necessitating reduced consumption of products and energy, and/or increased imports from other regions and/or intensified use of other sources such as landscape care wood, and wood originating from conservation management and short rotation coppice.

Promoting innovation and competitiveness

The fourth challenge identified by EFSOS II is to foster innovation and competitiveness. A more innovative approach in all parts of the sector could create, defend or expand markets, create new opportunities, reduce costs and increase profitability. There are particular opportunities, in the product field, for improved housing systems from composite wood products, bio-refineries, and 'intelligent paper'. Forest management also needs innovative approaches, for instance in developing new forms of recreation, new ways of financing biodiversity conservation or the provision of other ecosystem services. Developing a culture of innovation is a complex challenge, going far beyond the boundaries of the forest sector.

Future challenges for the sector

The European forest sector has some important policy driven challenges:

- Help to mitigate climate change by storing carbon in trees and in wood products, and substituting for non-renewable fuels and materials
- Promote renewable energy through the use of wood for bioenergy
- Halt and reverse the loss of biodiversity in Europe
- Promote innovation and competiveness in the European forest and wood sector in order to compete in an increasingly competitive global market.

Policies and institutions

Forest sector policies, institutions and instruments in Europe are, in general, stable, recent and effective (SoEF 2011). Increasingly the forest sector enjoys public support through the participatory nature of National Forest Programme (NFP) processes, which integrate the positions of the many concerned actors, and provide a basis for dialogue with other sectors on the major challenges of the day. However the challenges posed by climate change, energy and biodiversity issues are exceptionally complex and long term, and require quite profound changes if they are to be satisfactorily resolved. It will require a very high level of sophisticated cross-sectoral policy making, sharply focused policy instruments and strong political will to mobilise enough wood for energy, to implement the right balance between carbon sequestration and substitution and to conserve biodiversity without sacrificing wood supply. Will today's policies and institutions rise to the challenge? To do so will require much improved monitoring systems, the ability to reach consensus, inside and outside the sector, on complex issues, as well as the creation and implementation of sharply targeted policy instruments, which make the best possible use of limited government funds. High level political will is also necessary, to ensure that forest management is not only sustainable, but makes the best possible contribution to the sustainable development of society as a whole.

Living with storm damage in the EFSOS II futures

A main conclusion of EFSOS II is that demand for wood, and especially for energy wood, will continue to grow. This implies that when significant volumes of storm damaged wood arise, there will be a market for them, even if they are of low quality. Large scale marketing circuits for energy wood (in the form of chips or even of pellets), of the type being set up now, would be able to respond to sudden bursts in the supply of wood due to storms. Indeed, it might be prudent for national, or even international, groups to set up, in advance of the storms, flexible structures which could smooth the marketing of large volumes of salvage wood, helping them to find the highest value market. This could lessen the negative financial impact of storms, which, in most cases has hit the forest owner (private or public) hardest (see Chapter 3.2 and 3.3).

Wood supply is not the only function of forests, and perhaps the main theme of EFSOS II is that forest managers and policy makers must focus on combining and optimising the demands on forests, resolving tradeoffs in a rational manner. One of the issues to consider is the risk surrounding storm damage. In EFSOS II, this risk was included in the form of a risk indicator, based on the actual distribution of the forest over age classes and tree species. The higher the share of coniferous species and the higher the share of higher age classes, the higher the indicator. Therefore, scenarios with extended rotation lengths (biodiversity and carbon sequestration scenarios) generally scored higher on the wind risk indicator. There are at least two trade-offs specifically linked with storm damage:

- between salvage logging and leaving dead wood for biodiversity. Increased salvage logging after storms, which is desirable from the economic point of view as well as for controlling damage by secondary causes (insects), might negatively influence biodiversity. Decisions for salvage logging should take these aspects into account, aiming to leave an appropriate volume of deadwood in the forest. A decision support tool needs to be developed, so that it would be available immediately after a major storm damage
- between carbon sequestration and storage in the forest and increased storm risk. Some of the strategies to maximise the carbon stock in forest increase the risk of storm damage, which would of course abruptly decrease the carbon stock in the forest (see Chapter 3.1), negating the intention of the strategy. More needs to be known about risk and strategies to manage risk while optimising the flows of wood and carbon.

The future of forestry in Europe

On the basis of EFSOS II, and other studies of the outlook for the European forest sector, it is possible to draw a few general conclusions:

- Demand for the many goods and services of the forest will continue to increase, although the forest area will not expand much. This concerns not only wood raw material for industries, but wood for energy, recreation and other services (e.g. hunting, mushroom collection, etc.), and biodiversity. There is no question of reducing the forest's ability to supply protection to soil, water and infrastructure, and there are rapidly increasing complex and policy-driven demands for climate change mitigation, and renewable energy, which must be incorporated alongside the more traditional goods and services provided by the forest
- There are indications that despite much public ignorance of the true condition of European forests, European society is much attached to its forest and will oppose efforts to decrease its area or significantly intensify its management, if this implies a loss of biodiversity, landscape or recreation values. The national forest programmes developed in practically all European countries have identified a strong consensus on the objectives of forest policy, which vary widely between countries and regions. However there is little indication that Governments are willing to devote more public funds to forest related activities.
- These rising demands, some of which must be traded off against each other, combined with limited resources, challenge forest managers everywhere to find creative site-specific solutions combining these demands, in a broader national and international context, while maintaining public support for management choices by explaining options and consulting stakeholders.

Forestry and storms in the future

- The expanding demand for wood implies that there will probably be a market even for storm damaged timber, notably for energy
- There needs to be mechanisms and flexible systems established to get the highest prices possible for salvaged wood after storms in order to reduce the negative impacts on forest owners
- Following storms there is a balance required between salvage logging and leaving dead wood for biodiversity
- There is a trade-off between increasing carbon stocks in forests and increasing volumes at risk of being damaged by storms

Recommended reading

UNECE and FAO 2011 The European Forest Sector Outlook Study II 2010-2030. United Nations, New York and Geneva, 2011 (abbreviated to EFSOS II)

FOREST EUROPE, UNECE and FAO. 2011 State of Europe's Forests 2011. Status and trends in sustainable forest management in Europe. Oslo, 2011 (abbreviated to SoEF 2011)

Mantau et al. 2010. EUwood – Real potential for changes in growth and use of EU forests, Final report. Hamburg, 2010. Available from http://ec.europa.eu/energy/renewables/studies/doc/bioenergy/euwood_final_report.pdf

5.3.

Challenges for forestry in relation to storms

Yves Birot and Barry Gardiner

Increase of storm damage

Wind storms, as climatic events, cannot be predicted, prevented or controlled. However, there is some evidence that man-induced climate change may have led to increased peak wind speeds in Europe and changes to the trajectories of windstorms with an extension into Central and Eastern Europe. Model-based projections on future windstorm regimes are not entirely consistent but there are suggestions of possible increases in storm activity over certain parts of Europe, a reduction in the return periods of extreme events, and broader areas of damage (see Chapter 5.1 for more details). What is more certain is that climate change will directly affect forest vulnerability to storms for several reasons:

i) increased soil waterlogging in winter resulting in a lower tree stability due to reduced anchorage of the root system (most climate models forecast increased winter rainfall)
ii) accelerated tree growth in height and volume due to elevated CO_2 levels and N deposition and longer growing seasons
iii) impact of climatic change on pathogens affecting tree root systems
iv) longer periods of unfrozen soils during winter (of particular importance in Fennoscandia).

Slowing climate change through a drastic reduction of the level of greenhouse-gas emissions is desirable, but even if achieved, it would have delayed and partial effects on decreasing storm hazard outcomes in the foreseeable future. Therefore there is an urgency to act now.

> Climate change is likely to have most impact on the future risk to forests by increasing their vulnerability. This is because of the forecast increase in winter precipitation leading to more saturated soils and increasing temperatures with consequent reduced periods of frozen soils.

Detailed analysis of wind damage in European storms suggests that the observed increase in storm-related damage to forests is due to a combination of the changing climate and increasing vulnerability resulting from the forest management practices prevalent in Europe. This increased vulnerability of forest stands is related to the major forest and forestry changes that have occurred in the 20th Century, such as the extension of forest areas, reduced species composition favouring conifer monocultures, and increasing top height and standing volume (see Chapter 1). If growing stock keeps increasing in Europe, damage levels (by volume) are likely to at least double by the end of the century. Such an increase could have profound implications for forest health, carbon budgets, timber prices and the sustainability of the forestry sector. Therefore, active risk management needs to become an integral part of forestry in Europe. Options for risk management exist at a range of scales, such as silvicultural measures at the stand level to reduce vulnerability, arrangement of stands at the landscape scale to minimise edges at risk, and policies at the national and European level to prevent the European forest growing stock from further increase (and therefore the level of overall risk). Other options include insurance and contingency planning.

It is also possible that current trends in forest growing stock will change with the increasing demand for wood feedstock by industry (Chapter 5.2). Such changes would have a marked influence on damage levels if they reduced the standing volume of European forests and therefore reduced the level of risk.

Changes in forest area and forest management in the 20th century have been a major cause of the observed increase in storm-related damage to European forests. This paves the way to developing adequate forest management and planning measures capable of reducing this damage and to prevent its increase in the future.

Forest management

Eradicating storm-related forest risks is obviously not feasible, but the findings mentioned above show that forest managers and silviculturists have real opportunities to change forest vulnerability (Chapters 2.2 and 2.3). Therefore, the challenge for European forestry is to develop practical management strategies to reduce wind-related damage (Chapter 4.2). Box 5 gives some examples on how silviculture can be used for risk reduction.

For those species for which the vulnerability to wind damage increases rapidly with height and age it is worth modelling the wind damage risk to the stands and identifying the trade-offs between the risk of financial loss in the case of wind damage and the reduced income due to an early or premature harvest or other adapted silvicultural regimes (Chapter 4.1).

In the past coping with storm-related forest damage has been mainly looked at from the perspective of economic losses linked to timber production but not from the perspective of being an essential part of the dynamics of natural forest ecosystems. In an endeavour to develop more stable forest stands for the future, the question of the various roles and functions assigned to forests in relation to the full range of goods and services they provide should not be overlooked. For example, certain particularly vulnerable areas could be designated as forest reserves with the focus on biodiversity or recreation rather than on timber production.

Box 5. Three possible silvicultural options for storm-prone areas (see Chapter 4.2 for a more detailed discussion of the impact of silviculture and options for management)

i) Short rotation biomass production through plantations without thinning, with a single cut before the stand reaches a top height of 20 m. This option aims at creating wind resistance resulting from a "group effect" and minimising the time trees are at risk. It allows the production of small logs and wood for bioenergy, wood-based panels or pulp. However, this option can have some negative impact in terms of loss of biodiversity and soil fertility, as well as of income (e.g. lower price of wood, cost of fertilisation).

ii) High forest with low stocking through large spacing at planting and early and heavy thinning. This option leads to increased wind resistance resulting from the higher taper of trees and to large diameter logs, with however some reduced quality due to increased knottiness if no branch pruning is carried out.

iii) Selection forest with low stocking aimed at increased resilience by maintaining all diameter classes. This option eases the restoration after damage (no planting is required); however, it is not easy to implement in particular because of the logging and harvesting of small amounts of timber.

Reducing forest risk to storms can be achieved by: improving the wind-resistance of trees and stands, limiting the values at stake, and increasing the resilience of the whole forest system.

Forest planning

The recent progresses in understanding the processes driving the interactions between the wind and trees, from individual trees to the whole landscape (even with heterogeneous patterns), allows the development of forest planning methods which optimize the spatiotemporal organization of cuttings and minimizes the fragmentation of the forest resulting from many small clear-felling areas, which overall creates long lengths of vulnerable new edges (Chapter 2.1). The challenge is to implement such plans at the landscape scale and in particular when there are multiple forest owners with differing objectives. This requires careful discussion, negotiation and compromise and the use of all the scientific aids available to demonstrate the consequences of different management options on the vulnerability of the whole forest over an extended period. Methods for developing consensus between all forest stakeholders will become even more important (Chapters 3.4 and 4.4).

It is also essential to limit the number of over-mature stands, particular in areas with high wind exposure. This remark is particularly important in the European context where there is a clear and continuous trend over the last few decades in increasing both the age of final cut and the standing volume in most regions.

It might be necessary in some locations in the forest landscape that are particularly at risk to adopt specific silvicultural regimes (Chapter 4.2 and Box 5). Such approaches, aimed at decreasing the vulnerability to the wind and the values at stake, can be efficient from an economic point of view and are becoming more attractive with the expected increasing demand for biomass in a carbon neutral bio-economy. However such strategies may conflict with other objectives assigned to forests such as biodiversity and carbon sequestration into forest ecosystems. At the same time less conservative approaches, which allow for longer rotations and will increase the storage of carbon, need to take account of the huge release of carbon resulting from catastrophic wind damage as discussed in Chapter 3.1. Again, all these issues require careful consideration of the trade-offs being made and need to be considered as part of the planning process.

Forest planning also needs to take into account other risks, related or not to climate change (e.g. drought, heat waves, fire, pests and disease, invasive species), and of course the wood production function of the forest, which in turn has social and economic impacts on the whole forestry wood chain, the environment, the forest culture, and the policy and politics at the local, national and supra-national level. This observation suggests the need to undertake foresight studies at the regional level. Starting from a review of the historical background, the current situation, and various scenarios for the future, such studies would allow identification of the relevant challenges and issues and the need for alternative solutions to address them, and evaluate these options against a set of clearly defined and agreed criteria. Such analysis needs to be carried out prior to a storm and not in the immediate aftermath when it is extremely difficult to make balanced judgements (see Figure 26 in Chapter 4.1 for a schematic representation of this process). Tailored analyses would need to be carried out for different regions of a country in partnership with the responsible bodies in neighbouring regions and countries (the largest storms can affect wide areas) and updated at regular intervals (e.g. 5 years) as priorities change. Such foresight studies would form the basis for successful restoration of the forest after a storm as discussed above.

Active risk aware management integrating all risks to forests (abiotic and biotic) should become part of standard forest practice in Europe. Regional approaches should be undertaken on the basis of foresight studies.

The occurrence of storm damage may be a good moment to re-evaluate species choice and forest structure and to select tree species which fit the site conditions (soil characteristics in particular) and which are known to be wind resistant or wind tolerant. Storm damage may therefore provide an opportunity to plan and implement a long term future for a forest with a wider range of benefits. The occurrence of storm damage can also be an opportunity to evaluate the management systems within a forest and to adopt new methods for measuring and monitoring the forest and assessing the level of wind risk as discussed in the section on risk mitigation (Chapter 4.1).

Dealing with the aftermath of a storm may also accelerate the introduction of new technologies for handling timber such as the use of mechanised harvesters, which can be economically beneficial in the long-term. This was the case after Storm Martin in 1999 in the Aquitaine Region of France where all harvesting is now fully mechanised. It can also provide the possibility for investing in forest infra-structure such as improved landing stages and forest roads, and the building of wet storage areas for timber in order to be better prepared for the next storm (Chapter 4.3).

Storm damage to forests should not always be regarded as only a problem but also as an essential element of the dynamics of natural forest ecosystems. Such occasions provide an opportunity to reassess the objectives for a forest and how the forest is managed. It can be the opportunity to introduce new management practices, to use new establishment and harvesting techniques, to introduce a more diverse species mix, to set aside vulnerable areas for biodiversity or recreation rather than timber production, and to establish contingency plans and infra-structure ahead of future storms.

Forest restoration and financial support

The issues discussed above mean that restoration of the forest after a storm requires careful consideration and planning, and ideally restoration plans will have been prepared ahead of the storm when it is possible to take a more balanced view. Forest restoration is discussed in Chapters 3.2 and 4.3 and the key requirements are to work to an agreed plan and to focus on ensuring there are the facilities and capacity to access the forest, supply new plants or seeds, and to successfully establish the forest in the face of likely increased deer and insect browsing. This will probably require repairs to roads, financial support for local nurseries affected by the storm, the use of deer fencing, and increased monitoring of the restored forest. This is all dependent on financial assistance, which is why rapid access to regional, national and European restoration funds is so important (Chapter 4.1 and 4.3).

Forest restoration after a storm is a vital part of the Recovery Stage of Forest Risk Management. Restoration should be based on plans developed in advance of the storm and updated on a minimum of a 5 year cycle. The key requirements will be to enable access to the forest and to a supply of seedlings or seed, and the protection of the new forest areas against probable increased deer and insect pressure. Successful restoration requires rapid access to funding from regional, national and European sources.

The public financial measures that are so important in forest restoration are not an alternative to private insurance systems. The two solutions are complementary in circumstances when the consequences of storm damage are high at the regional level. Indeed, when the total volume damaged by a storm exceeds the annual cut in a region then the whole forest economy is affected (Chapters 3.2 and 3.3) and requires decisions by the public authorities in order to collectively organise the salvage of damaged trees, to maintain prices, and to organize for the future (Chapter 4.3). Private insurance is generally more appropriate for local damage, which does not have repercussions on the round-wood market and forest economy. In the case of catastrophic events, the two systems, public and private, need to work together. Ideally, European Union Member States should start to work in partnership with insurance companies, to promote a harmonised and equitable insurance system across storm affected countries that properly compensates forest owners for their private losses.

Risk sharing systems through a combination of insurance, compensation, fiscal measures and specific funds require major improvements of the existing public/private partnership.

Policy recommendations

The study on "Destructive Storms in European Forests: Past and Forthcoming Impacts" (see Recommended Reading) has put forward very relevant recommendations regarding the development of policies and strategies for better addressing storm-related forest risk:

- *"Countries should develop forest storm risk management plans and procedures for dealing with the aftermath of storms. This could be facilitated by the provision of best practice information, guidelines and risk modelling tools at a single location in the languages of affected countries, and in the setting up of pre-storm training for harvesting machine operators and crews."* There would be a substantial added value if all information on dealing with storm damage across Europe could be brought together and shared.
- *"There is a clear requirement for the provision of a central source of up-to-date, appropriate and easily available information prior to and following storm events. Such information could consist of early warning systems for damaging storms, immediate maps of areas affected by storm damage using remote sensing, and the provision of information on global timber prices to assist in post-storm timber marketing."*
- *"There is an urgent need to harmonize the monitoring and reporting of storm damage and all other hazards (abiotic and biotic) across Europe. Only with such a harmonised approach will it be possible for policy makers to make informed decisions on the mechanisms and appropriate levels of response to different threats to European forests."* This should also be extended to restoration of stands after storms, and to careful evaluation of the different measures used in the years following storms, in order to improve the system.

Chapter 9 of "Destructive Storms in European Forests: Past and Forthcoming Impacts" goes into substantial detail on the policy issues for European member states and the European Commission. At national and regional levels there are clear needs for policies to be implemented to increase awareness of the risks of storm damage, in developing risk aware management practices, in making easily available best practice guidance and training, and in cooperation with forest owners and managers and emergency services to develop a crisis plan ahead of a future event (see Chapter 4.3 for more details). The European Commission itself should support member states by sharing best practice guidance and in making available data and tools for better forest risk management and crisis planning and preparation. In addition, following a storm, it has the potentially crucial role of enhancing post-storm coordination between affected countries and in facilitating the rapid response to storm damage by putting in place procedures to minimise storm impact. This could be, for example, by aiding the implementation of multilateral or bi-lateral cooperation plans following storms, triggering established plans and emergency measures to allow quick access to funds, and the rapid implementation of short-term derogation of regulations to allow immediate storm clear-up and forest restoration.

Management of storm-related forest risks would be greatly improved through the establishment of a European-wide platform or facility. This could provide policy-makers and managers the science-based, technical, and operational background information, including capacity building measures, to respond to the immediate and long-term requirements following a storm. The mandate of such a Facility should encompass all major abiotic and biotic risks.

Summary

It appears that a reasonable strategy with regard to forestry and storm damage is to:

i) understand the importance of storms as elements of the dynamics of natural forest ecosystems
ii) keep the storm risk at an acceptable level in terms of impact and damage mainly through preventive measures;
iii) set up efficient tools for sharing risks;
iv) be prepared to cope with storm related crises and their post-storm management;
v) have contingency plans to respond rapidly to storm damage to limit their economic, environmental and social impact;
vi) develop restoration methods which can create a future forest that is more stable and resilient ecologically and economically.

These objectives can all be addressed in a properly implemented Forest Risk Management plan as discussed in Chapter 4.1. The tools and knowledge already exist to develop such systems in European forests, as has been demonstrated in this book. The key requirement is for there to be sufficient priority given to the issue of storm damage at regional, national and supra-national levels.

Recommended reading

Birot, Y., Landmann, G. and Bonhême, I. (eds.). 2009. La forêt face aux tempêtes. Editions Quæ. Versailles Cedex, France. 420 p.

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