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Abiotic Stressor: Storms

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1. Introduction

Storms have been the predominating natural disturbance that seriously affected the forest ecosystems in Europe. Storms tend to occur more frequently and intensively, leading to more serious damages in recent decades. Over 130 separate storm events that induced noticeable damages to forests were identified during 1950 – 2010 [1]. Based on the percentage of growing stock that were damaged, 11 most catastrophic windthrows were identified: January 1953, September 1967, September 1969, November 1972, October 1987, January-March 1990, December 1999, November 2004, January 2005, January 2007, January 2009. The total damage by various disturbances to Europe forests is illustrated in Figure 1[3], from which it can be easily identified that windthrows is the most significant nature disturbances. As regard to seasonal distribution of storm events, winter storms are more common than summer storms. The overwhelmingly majority of storm damages were found between November and January. It is also important to notice that some storm events might not make significant damage in large areas, but could also be extremely devastating at local level, causing catastrophic losses to local forest owners at a certain region.

2. Historical storm damage in Alpine space member states

Data on timber harvest records from four countries (Austria, Germany (Baden-Württemberg), Italy (Bolzano) and Slovenia) were used in order to determine how in a recent history the storms affected forests of the Alpine region. Available data dates back to year 2000 till 2010 and includes information on volume of trees that were logged during the specific year because of storm (wind) damages (LIT: see regional reports for details). Those data are usually related with forest management units but for this analysis the data were summarized to NUTS 3 level [2]. The common time span for all four countries was from 2002 to 2008. The data presented

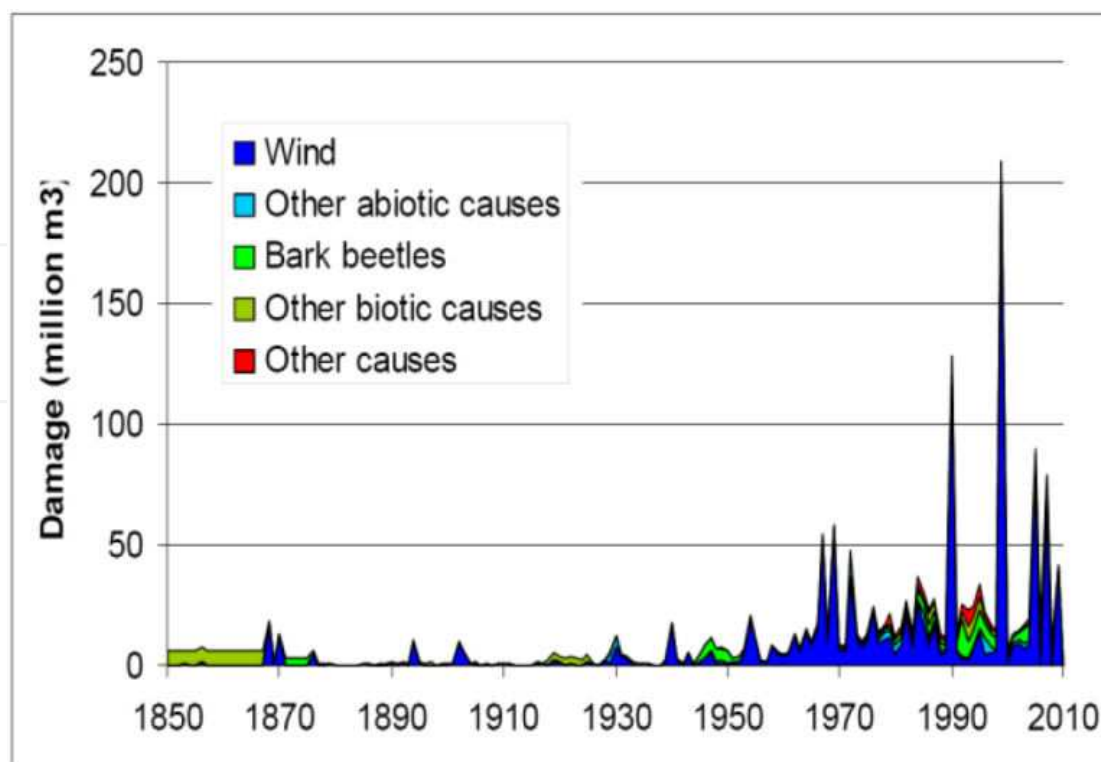


Figure 1. Total damages to European forests (Retrieved from Schelhaas 2008a)

in the graph (Figure 2) shows the volume of trees that were cut because of storm damage. The volume is strongly influenced by the area of forests so the main purpose of the graph is just to show some extreme years. In Austria those were 2002, 2007 and 2008; in Baden-Württemberg 2000, 2001, 2003 and 2007, in Bolzano 2003 and 2005; in Slovenia 2008. All together in eight years (from 2002 till 2008) for those regions more than 30 million m³ of wood (trees) was registered to be cut because of storm damages.

The forest area at each NUTS 3 region differs greatly. Total volume of cuts per unit (NUTS 3 region, country etc.) was divided by its corresponding area of forest to avoid the influence of area on the volume of logged trees. With unit value per hectare ("m³/ha of forest" or with multiplying it with 100 to "m³/100 ha of forest") it is possible to compare timber data between different NUTS 3 regions and between years.

Forest areas were calculated from CORINE Land Cover maps, which were produced in 2000 [3] and then updated in 2006 [4]. For selected NUTS 3 regions from year 2000 to 2006 the area of mixed forest has decreased from 2,291,285 ha in year 2000 to 2,150,907 ha in 2006 which represented a decline of 140,378 ha. On the contrary the area of coniferous and broadleaved forests has increased by 39,213 ha (from 3,412,648 to 3,451,861 ha) and by 66,587 ha (1,097,571 to 1,164,158 ha). All together the area of forests in selected countries has decreased by 34,578 ha in the period between 2000 and 2006. With the interpolation of those changes between year 2000 and 2006 the interpolation for each NUTS 3 region for period 2000 to 2010 was done. The aim was to get some robust information on the area of forest per NUTS 3 region in each year.

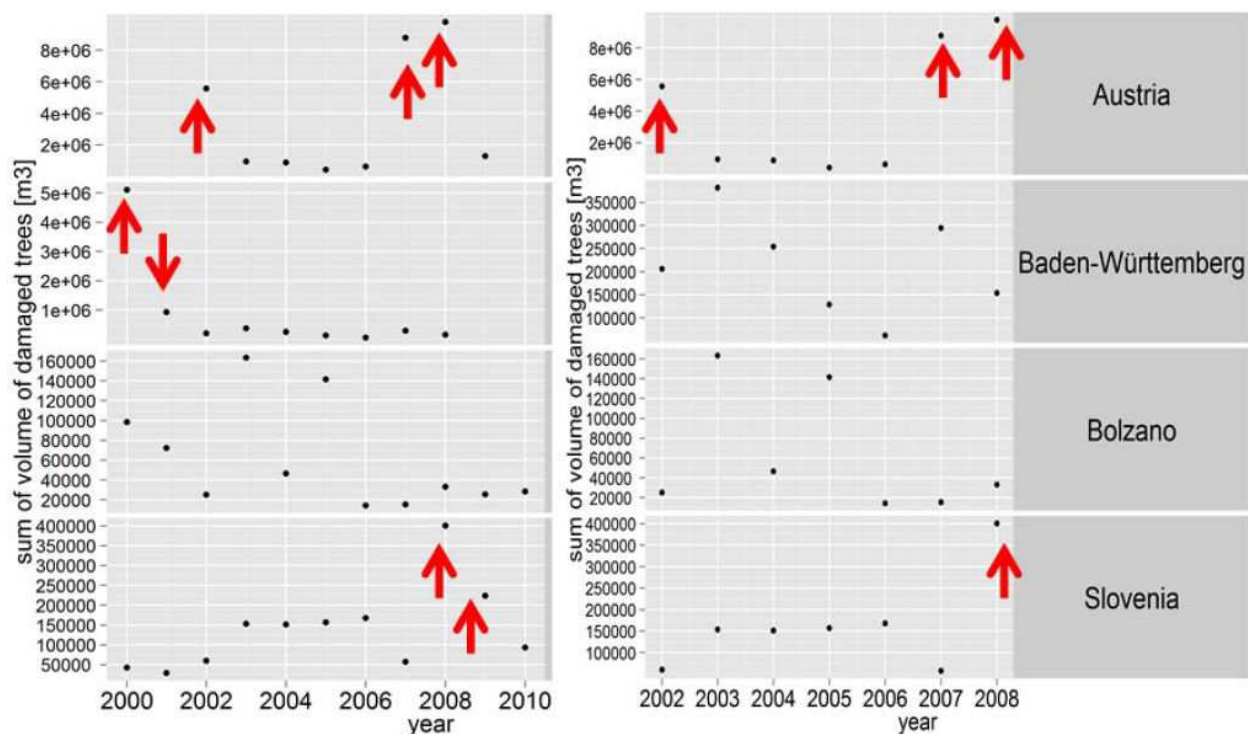


Figure 2. Sum of m3 of timber harvested because of storm damages per year for all available years (left) and for the jointly time span (right). The values on the y axis are due to big differences between countries not the same.

For the period from 2000 to 2010 the annual mean value of damages because of storm on NUTS 3 level was 66 m3 on 100 ha of forest. The median was much lower 11.45 m3 on 100 ha of forest which shows that in this time span there were some very big damaging events in some of the forests in Alpine Space countries. From the maps below it is possible to recognize which NUTS 3 regions were more exposed to storm damages in the forests during the period 2000 - 2010. If the country is not coloured there was no data for selected year. The used thresholds (see Table 1) were calculated from the whole dataset (all regions and all years) and then divided to four quantiles. The 4th quantile was further divided on the 90th percentile and 99th percentile. So the 99th percentile would mean that 99 % of all data on cuts in region from 2000 to 2010 were smaller than 1106.778 m3 per 100 ha of forest. With these subdivisions it is possible to identify also those regions with extremely large amount of damaged trees in selected year in comparison to other regions.

From the maps (Figure 3) it is possible to see some spatial and time patterns how the forests in selected countries of Alpine Space were affected by storms in the period from 2000 to 2010. From the maps and graphs (Figure 4 and Figure 5) it is possible to identify two peaks: first one during years 2000 to 2002 (when a big influence of windstorm Lothar especially in region Baden-Württemberg was noticed) and second one in 2007 and 2008 when forests in central Austria and north Slovenia suffered more severe storm damages. In those two years in all regions (Baden-Württemberg, Bolzano, Austria and Slovenia) together almost 20 million m3 of trees were cut because of storm damages.

Rang	Colour	Calculated threshold	Damaged timber [m³/100 ha of forest]
1		25 %	0 – 3.785
2		50 % (median)	3.786 – 11.450
3		75 %	11.451 – 31.904
4		90 %	31.905 – 111.982
5		99 %	111.983 – 1106.777
6			> 1106.778

Table 1. Legend: Map of NUTS 3 regions with calculated cuts on 100 ha of forest per year.

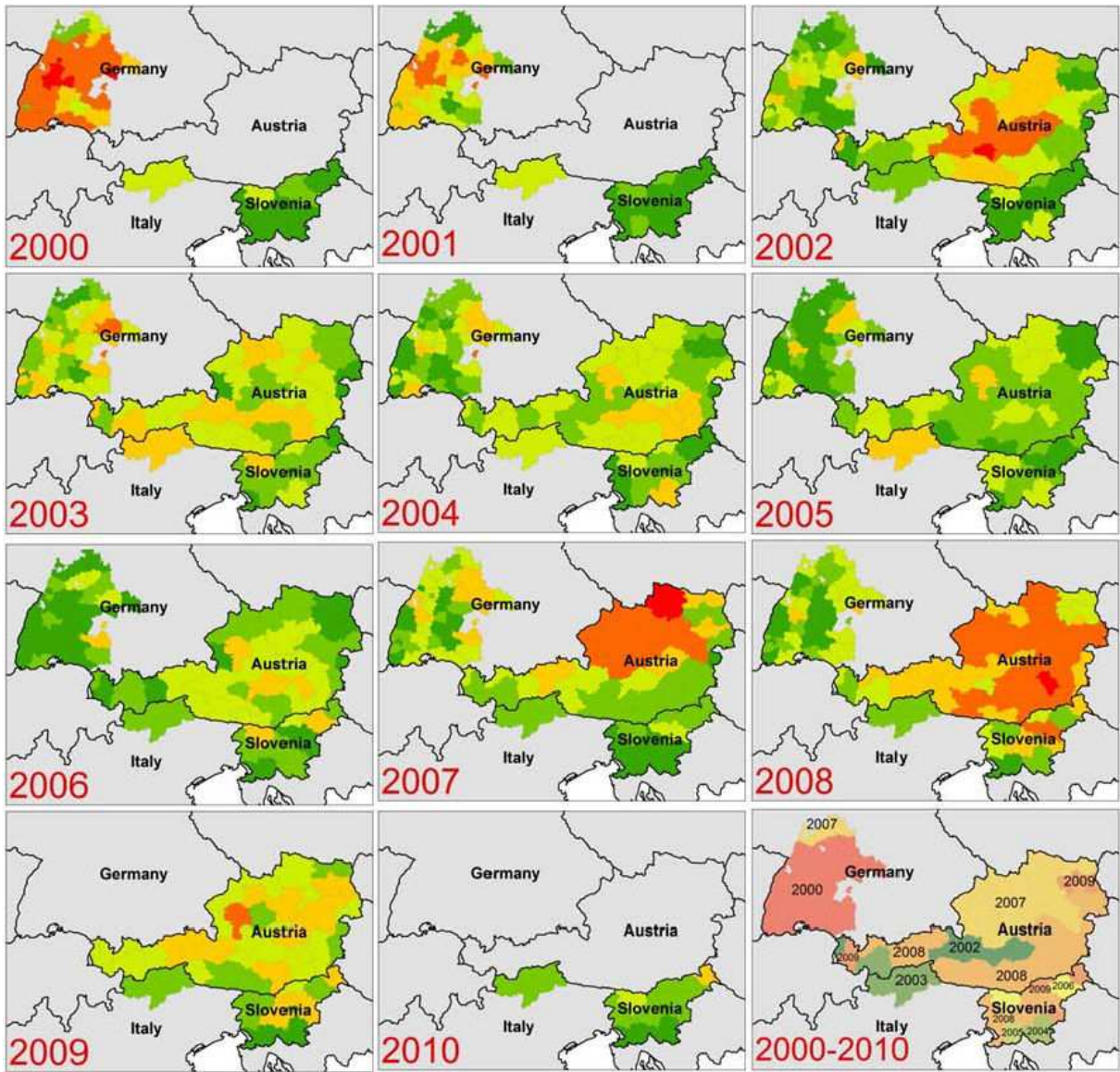


Figure 3. Maps of NUTS 3 regions with the information on volume of cut trees that were damaged by storms [m³/100 ha of forest]

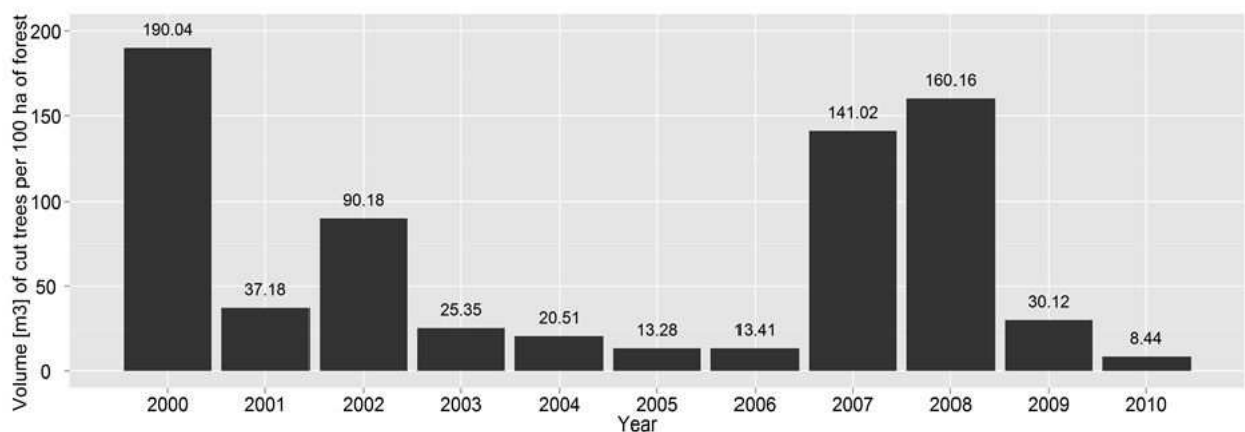


Figure 4. Volume of trees that were logged because of storm damage in the period from 2000 to 2010. With the goal to make data comparable between years. For each year the sum of cut trees was divided with the area of forest for same year and multiplied with 100, so the values are in m3 per 100 ha of forest.

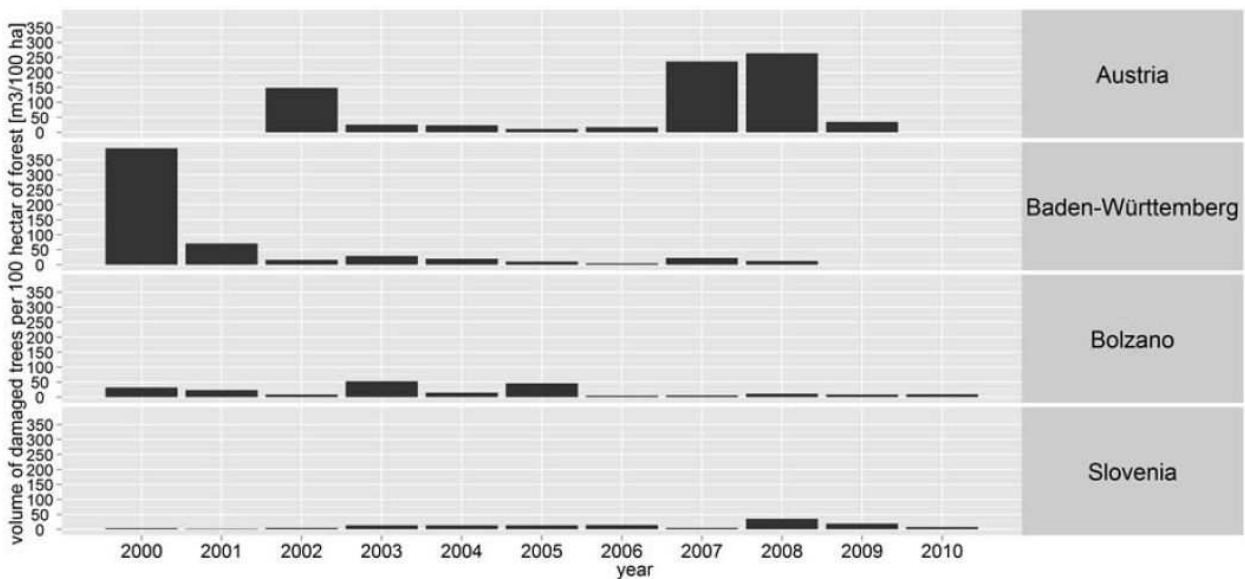


Figure 5. Volume of trees that were logged because of storm damage in the period from 2000 till 2010 divided on regions (country)

During the period between 2000 and 2010 there was eight NUTS 3 regions in which, because of storm damages, more than 1,100 m3 of trees per 100 ha of forest were cut. All of them are located in Germany and in Austria and only one is located directly in the Alps (Figure 6, Table 1). Considering common time span for all selected regions (from 2002 to 2008) it shows that because of storm damages in recent years (2007 and 2008) almost 65 % of all volume which has been recorded in timber harvest records was cut. The available data set illustrated that there were two extremely stormy periods (2000 and 2007/08) with high volumes of storm-damaged trees in harvest records, but the period of available data in this analysis is too short to predict if the storm damages in the forests of selected countries are increasing. Also reviewed literature

on historical storm damages in EU show that some of the authors conclude that the forest damages because of storms are increasing [5, 6, 7] and there has been also various studies of the historical wind climate which conclude that the increasing is not significant but there are significant fluctuations between decades [8] (Dorland et al., 1999).

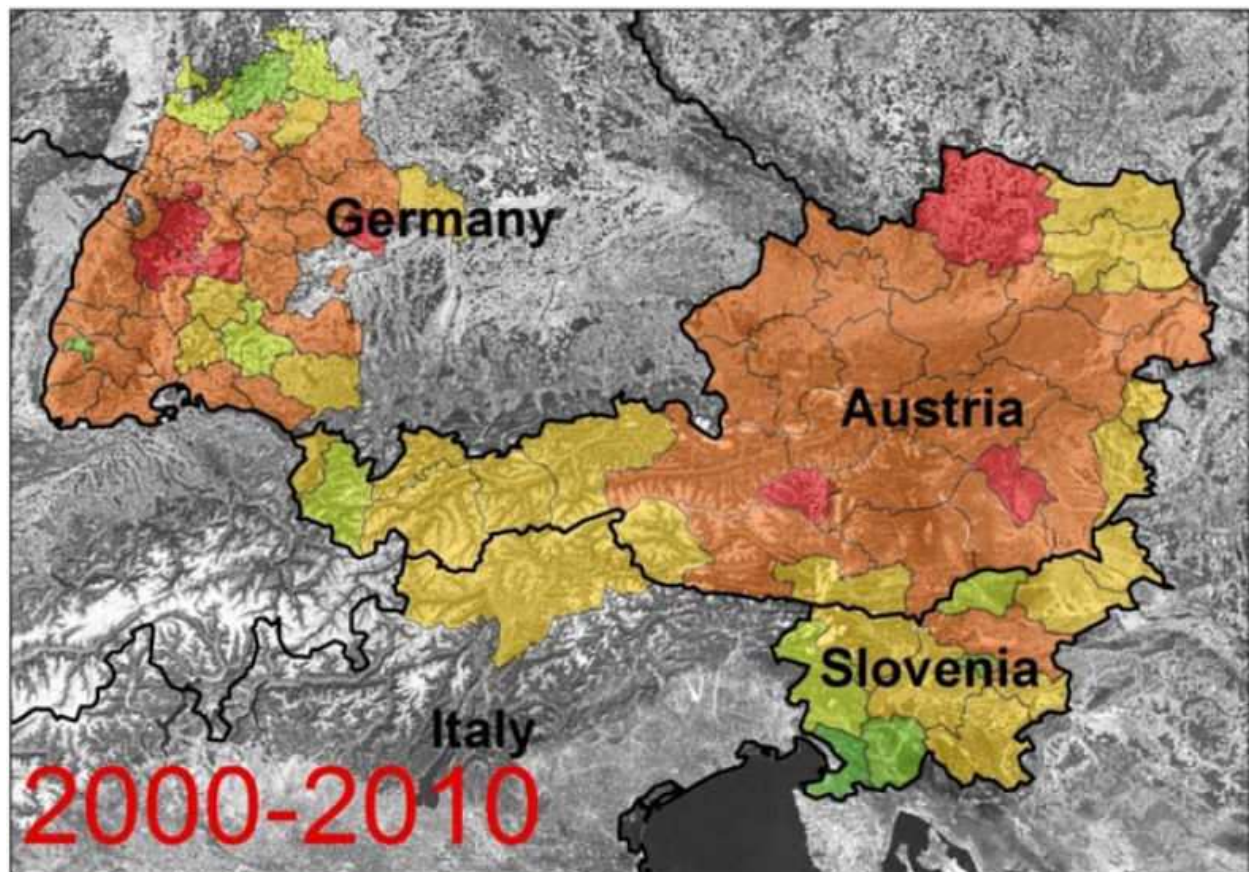


Figure 6. NUTS 3 regions with maximum volumes of cut trees [$\text{m}^3/100$ ha of forest] because of storm damage between years 2000 and 201

3. Contributing factors

It is clear that forest storm damages are triggered by many factors. This study tried to analyze some of the most contributing factors under commonly recognized forest and climatic conditions, aiming at provoking actions and plans to reduce storm risks and formulating strategies to adapt alpine space mountain forests to changing climate in the foreseeable future.

3.1. Tree height

Among other factors, tree height is one of the most sensitive factors contributing to the damage probability. Both statistical models [9,10] and mechanistic models [11] concluded the same

results that damage probability goes up along with increasing tree height. Schmidt et al (2010) simulated the change pattern of damage probability for Norway spruce with varying tree heights (see Figure 7). The model [13] was run by varying only tree height and DBH to maintain the fixed Height-DBH-ratio as 80 cm/cm, while keeping other predictors constant. This means the “standard” Norway spruce is assumed to be exposed to the same topographic exposition. The Numbers at the right side indicates 5 different locations in Baden-Württemberg, which stands for 5 different wind field characteristics. As a consequence, the overall trend of increasing damage probability with tree height going up is common in various geographical locations.

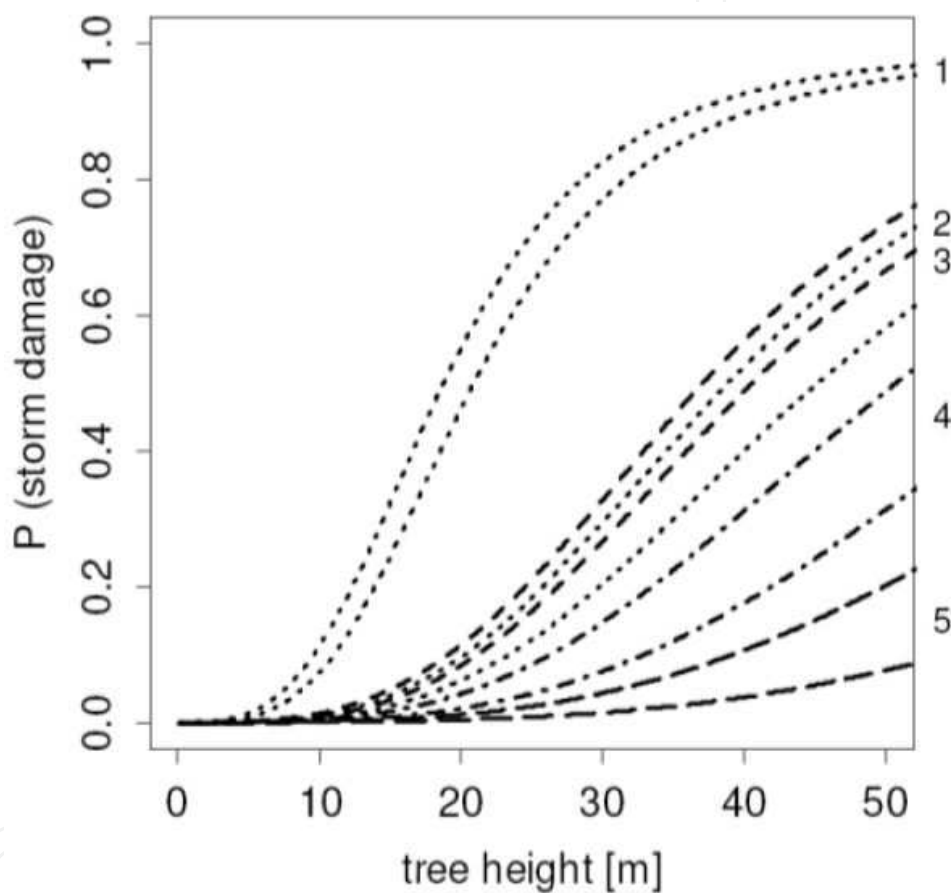


Figure 7. Impacts of tree height on storm damage probability (Retrieved from Schmidt et al.2010)

3.2. Tree species

In general, conifers are more vulnerable than deciduous trees in winter storm, whilst conifers might be less vulnerable than deciduous trees in summer thunder storms. The historical storm data is also in favor of this rule (see Figure 8). It has shown that there is a significant positive correlation ($p=0$, $P\delta = 0.381$) between the volume of damage trees and the percentage of coniferous forest in NUTS 3 regions. The higher the percentage of coniferous forest is, the larger the volume of damaged trees is. In contrary with the increasing of area with broad leaved

forests ($p=0$, $P\delta = -0.381$), which are apparently much more resistant to the damages produced by storms, the amount of damaged wood decreases. Some other authors [12,13] also came to the similar results who also discuss that coniferous species are considered more vulnerable to wind damage than broadleaved species, with Norway spruce (*Picea abies* (L.) Karst) being regarded as particularly vulnerable.

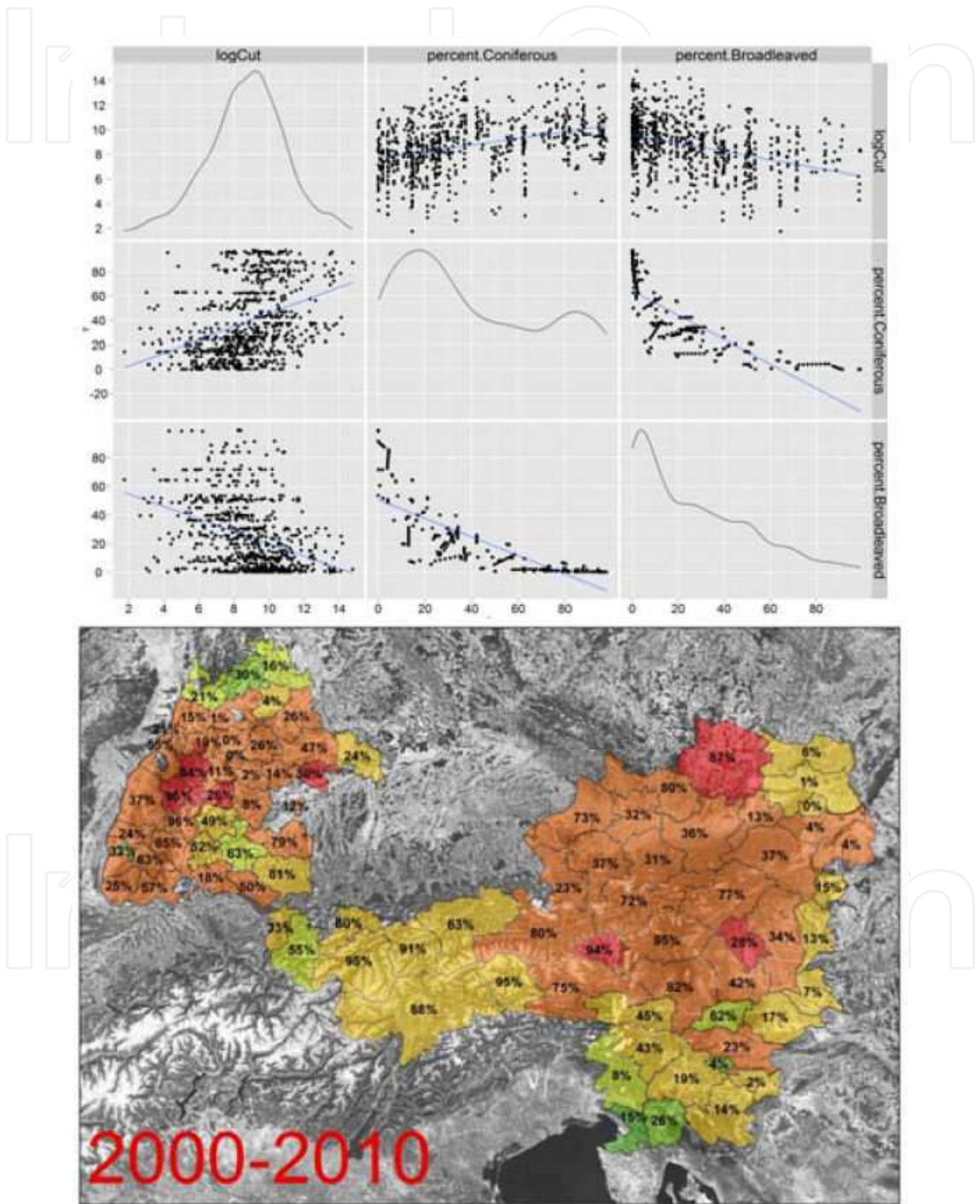


Figure 8. Percent of coniferous forest in 2006 (EEA,2006)and the NUTS 3 regions with maximum volumes of cut trees [$m^3/100$ ha of forest] because of storm damage between years 2000 and 2010.

In terms of species' susceptibility to storms, some statistical studies showed that spruce and silver fir are the most and least vulnerable conifers, and poplar and oak for the broadleaves, respectively [2]. According to a robust statistical model developed by Schmidt et al [13], the predicted damage probability under *ceteris paribus* condition indicated that the ranking from highest to lowest damage probability is: Norway spruce, silver fir/douglas fir, scots pine/larch, beech/oak, and then other broadleaves. When the interaction between height and species are taken into consideration at the same time, the two species groups, e.g. Silver fir/ Douglas fir and Scots pine/larches showed higher damage probability than Norway spruce at lower tree heights, but lower damage probability at higher tree height [13]. Many other experts have also studied on the resistance of different species to windthrows and obtained somehow contradictory results [14,15,16,17]. This on the other hand reflects the fact that trees' vulnerability to windthrows depends on various factors, including, but are not limited to, stands structure, forest management, site condition, soil condition, and meteorological differences and so on. Nevertheless, even-green conifers are in general more sensitive to windthrows than deciduous trees, especially during winter storms.

3.3. Stand structure

According the report of European Commission, stand structure has no clear straightforward correlation with storm damage [2]. Although it is commonly expected that the interpenetration of the crowns, complex social structure of trees with stands and vertical stratification of rooting system could enhance the ability of stands to resist against storm, there is no clear conclusion on the effect of stand mixture on stability of stands [2]. Whether a stand with mixed tree species can have positive influence on stand stability is also controversial. Slodicak 1995 [18] and Schütz et al. 2006 [16] found out species mixture has positive effects, while others did not draw such conclusion on the beneficial impacts of mixture [19,20].

3.4. Soil condition

Different soil conditions have largely differing impacts on storm damages. For example, Silin et al 2000 argued that forest soils that are deeply frozen in winter in North Europe are less vulnerable to windthrows, while moist soils with water saturation are more sensitive to wind [10]. Soil types and profiles determine its ability to resist wind damage too. For instance, Bock et al. [21] found out large damaged beech stands on superficial calcareous soils in Lorraine in Northeast France during Lothar 1999. As a matter of fact, forest stands that have deep rooting system and better root anchorage on frozen, not-saturated soils can reduce significantly the level of damage.

3.5. Topography

Schmidt et al 2010 developed a sound statistical model to explore the influence of local topographic exposure to air flow on storm damage probability at individual tree level based on the National Forest Inventory 2002 data, which was the best database to record the Lothar 1999 damages. The importance of each topographical exposure (TOPEX) index at various directions depends largely on major wind direction and aspects and exposure of forest stands

to wind direction. For example, the Lothar crossed the state of Baden-Württemberg mainly from southwest to northeast. Therefore, the model [13] that was developed only using the Lothar damage data also show higher coefficient of the TOPEX index with this same direction as Lothar's track than other TOPEX index. This is to say, forest stands locating on the top of northwest to southeast running ridges would have higher damage probability than other topographical locations, given the same tree-related information and the same wind field variables.

3.6. Wind speed

Wind speed is one of the most dominating meteorological factors that is positively correlated to the potential storm damage magnitude. The levels of storm damages was classified into several categories based on the maximal gust wind speed: no appreciated damage, moderate levels of damage, high levels of damage and severe levels of damage which is defined by the percentage of damaged woods in the national growing stock [2]. On the other hand, the time duration of storm over a certain area also plays a key role in the total damage. Equally important is that the local natural and climatic condition can influence considerably the levels of damage, since trees can acclimate themselves to windy characteristics by adapting their rooting system to improve the root anchorage to resist against the windthrows [22]. As a consequence, more severe damages could possibly be found in areas where strong winds are common climate phenomenon than those areas with quite few strong winds, when these areas are exposed to the same storm event. High wind speed penetrate more into the inland countries in alpine space, not only the coastal countries, like Lothar, the gust wind speed peak reached up to 51 m/s and 64 m/m in Baden-Württemberg and in Switzerland, respectively¹. This might put eastern alpine space member states under highly potential storm damage risks in the future.

4. Storm damage under changing climate

Firstly, the storm intensity is increasing. Leckebush et al. [23] developed an index to predict the storm severity for the past decades (1960-2000) and for the future under 2 climate change scenarios (SRES Scenarios A1B and A2). Both estimates showed the trend of increasing storm intensity. Not only had the projection indicated this tendency, but also the measured data. For example, in Switzerland, the measurement of wind gust speeds has also increased strongly since the beginning of records in 1933 [24]. Another tendency is that the hurricanes originated from Atlantic oceans tend to travel far further into the mainland of Europe with wider path. Although the 1999 lothar did not induced serious damage to southern and southeastern regions of alpine mountain, the alpine ridge might not be able to serve as a shield in the near future. This is to say, central Europe will be possibly exposed to larger storm damages as is different from the past. Regarding the return period of

¹ http://en.wikipedia.org/wiki/Cyclone_Lothar

devastating storms, Della-Marta and Pinto [25] also stated that it will be reduced as a consequence of increasing storm intensity.

Secondly, climatic characteristic is also a crucial factor leading to the storm damage variations. Temperature and precipitation are the most influential climatic factors. As explained in the previous section, unfrozen soil imposes potentially higher risk to forest stands during windthrow events. With the increasing temperature due to global warming, the unfrozen period in winter especially in northern Alpine space at high latitude will likely to be extended in the future, which makes the forests even less resistant to windthrows. Heavy rains are normally accompanied to big storm events either in the preceding days of or during hurricanes. This evidence was found in many unforgettable storm events in Europe, like Vivian & Wiebke 1990, Lothar 1999. Under the tendency of climate change, precipitation in winter is expected to be increasing, which result in moister soil. As a consequence, the water-logged soil will further weaken the ability of forest soil to stand against storm damage. Therefore, the damage could be expected to be more serious in winter in the future than it is now.

However, it is also important to point out that a meteorologically strong storm event does not necessarily induce catastrophic forest damages. It is highly dependent on the actual forest conditions, e.g. the growing stock at the time of storm. The most devastating ever storm Lothar has triggered enormous damages in Europe, which was partly due to the well forest growth and increment in standing volume in the past decades before the storm event. It can be foreseen that the damage magnitude would be the same or higher if the forests continue to grow with less cuts, leading the net increase of growing stock. Otherwise, the serious damage could be mitigated if appropriate forest management regimes are to be implemented. On the other hand, trees can acclimate to windy condition by strengthening their anchorage [24], so a storm might cause more serious damages in an area where high wind speed is rare than those areas with high wind speed as a common phenomena. Taking into consideration the different resistance capacity of different species to storm damage, silviculture strategies is also being adapted in many countries. For example, the damage inventory showed that 85% of damaged woods by Lothar in the German state of Baden-Württemberg were conifer species. After Lothar, more storm proof deciduous tress or mixed stands are planned for the regeneration in order to prevent storm damages. The goal of the share of species composition will be half deciduous and half conifer, with the aim to minimize the potential loss by future strong storm events.

Forest storm damage changes over time can be projected using different forest growth model and climate change scenarios. Schelhaas et al. [4] made a great effort to estimate the future storm damages for the whole EU27 plus Norway and Switzerland by multiplying the predicted growing stock by the observed percentage of annual storm damage between 1950 and 2010, as well as the percentage of maximum damage during 1950-2010. Two forest management scenarios were applied, e.g. business as usual and high demand. The estimation was made under the assumption of no changes in wind climate and no changes in vulnerability due to changes in age class distribution. The results showed that the annual average damage will increase from 17.5 Mil.m³ in 2000 to 31.0 Mil.m³ or to 24.1 Mil.m³ by 2050 under these two

management scenarios, respectively. This is equal to 78% and 38% increase of annual damage by 2050 [4]. Even though these estimates were made for the whole Europe forests, the Alpine space forests as a core component of the European forests are expected to experience the similar damage changes.

In accordance with the trend of higher temperature, more precipitation, more intensive storm activities, the storm damage in forests can be expected to be substantially increasing by the end of this century. Gardinar et al [2] stated that it is expected to be at least double under these climatic trends together with even-growing and ageing forest standing volumes. However, projections are always accompanied by uncertainties. Various forest growth models produce varying results. In General, under warmer climate in the future particularly in the north Alpine regions, higher temperate provides good conditions for trees to grow faster, which might aggravate the damage levels under the same annual harvest amounts. The forest harvest practice can be altered by forest policies and planning or even policies beyond forest sectors. For example, if more agricultural land is need for some reasons, wooded land might be cleared, or if bio-energy is becoming more demanding, requiring more woods for power generation, then the annual harvest will go up sharply, leading to slow net increment in growing stock. This in turn reduces the potential storm damage risk. In other words, apart from the impact of natural climatic changes on storm damages, anthropogenic interventions is also of great influence on future storm damages.

Drawing on the Lothar model (Schmidt et al. 2010), two exemplary storm risk maps are made for the second case study region in the context of MANFRED project, which is a joint trans-national area consisting of Ravensburg (Baden-Württemberg, Germany), Allgäu (Bavaria, Germany) and Vorarlberg (Austria). The risk maps illustrate the storm damage (either stem broken or uprooted) probability at single tree level. The color shifting from green to red indicates the damage probability increases. In order to compare the impact of two climatic characteristics, e.g. wind speed, the risk maps were made for pre-defined model trees, e.g. Norway spruce with height 40 meters, DBH 53 cm. The upper map (Figure 9) shows the potential risk of the model Norway spruce when it is exposed to high wind speed at each specific real topographic features. The lower map (Figure 10) deliver the same message under moderate wind speed scenario at the same geographical location. Figure 9 tells us that Norway spruce would be under very high risk to be damaged if a future storm event with similar wind flow characteristics as Lothar would hit this case study region.

When storm damages to other sectors are also taken into account, global and regional climatic models showed the consistent trend of increasing damages. For the perspective of insurance industry, a joint study by Swiss Re and the Swiss Federal Institute of Technology (ETH) Zürich found out that winter storms in Europe will cause a 16%-68% increase in average annual loss over the period 1975-2085 in constant currency depending on models applied [26]. In monetary term, the annual insured loss from winter storms would be 3.5 billion Euros in 2085. The effect of climate change will also result in greatly differing storm damages in various countries. For instance, Germany is expected to suffer insured loss almost three times the corresponding European value [28].

Storm Damage Risk Map in 2nd Case Study region --- Scenario: High Wind Speed

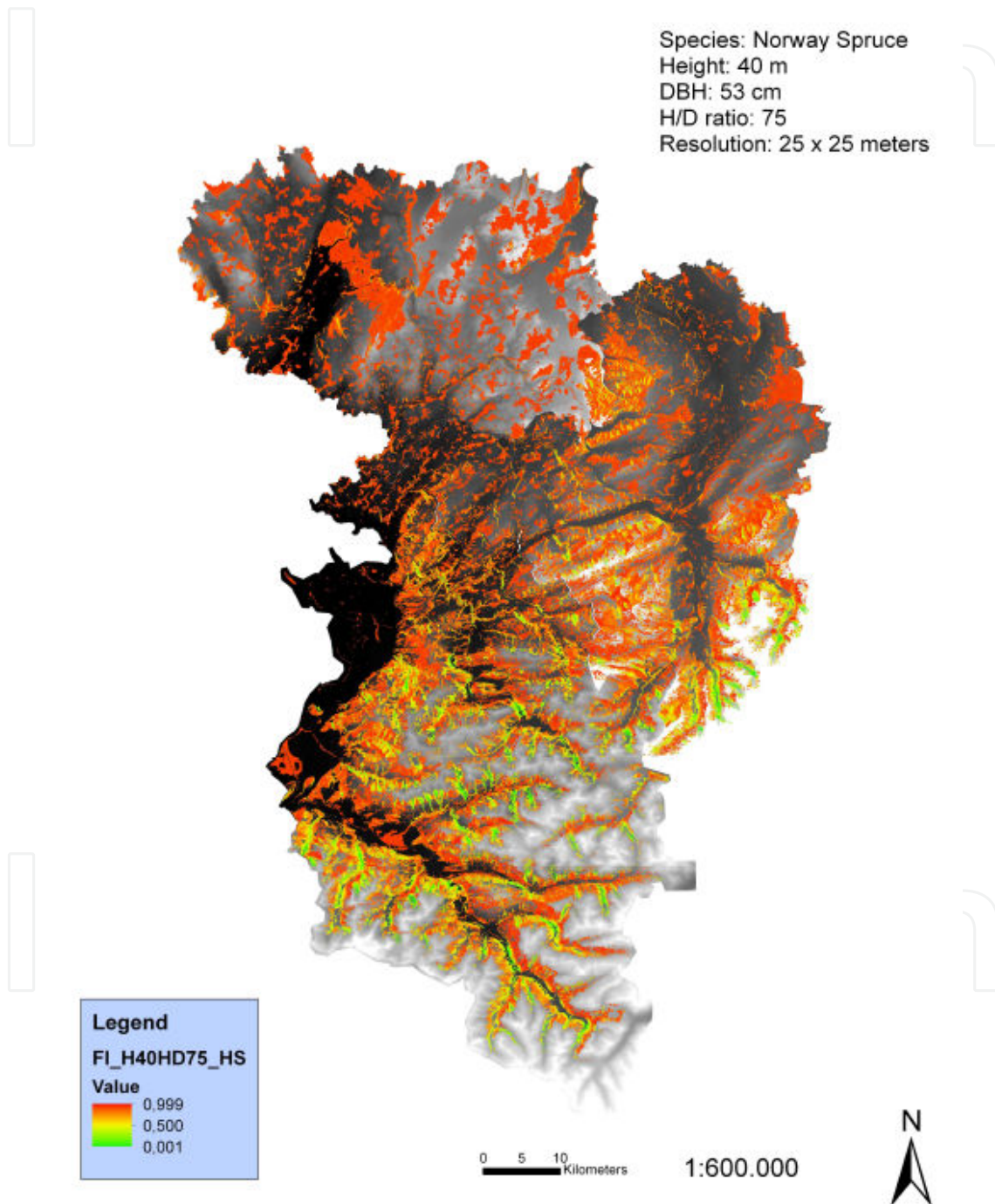


Figure 9. Storm damage probability under high speed scenario

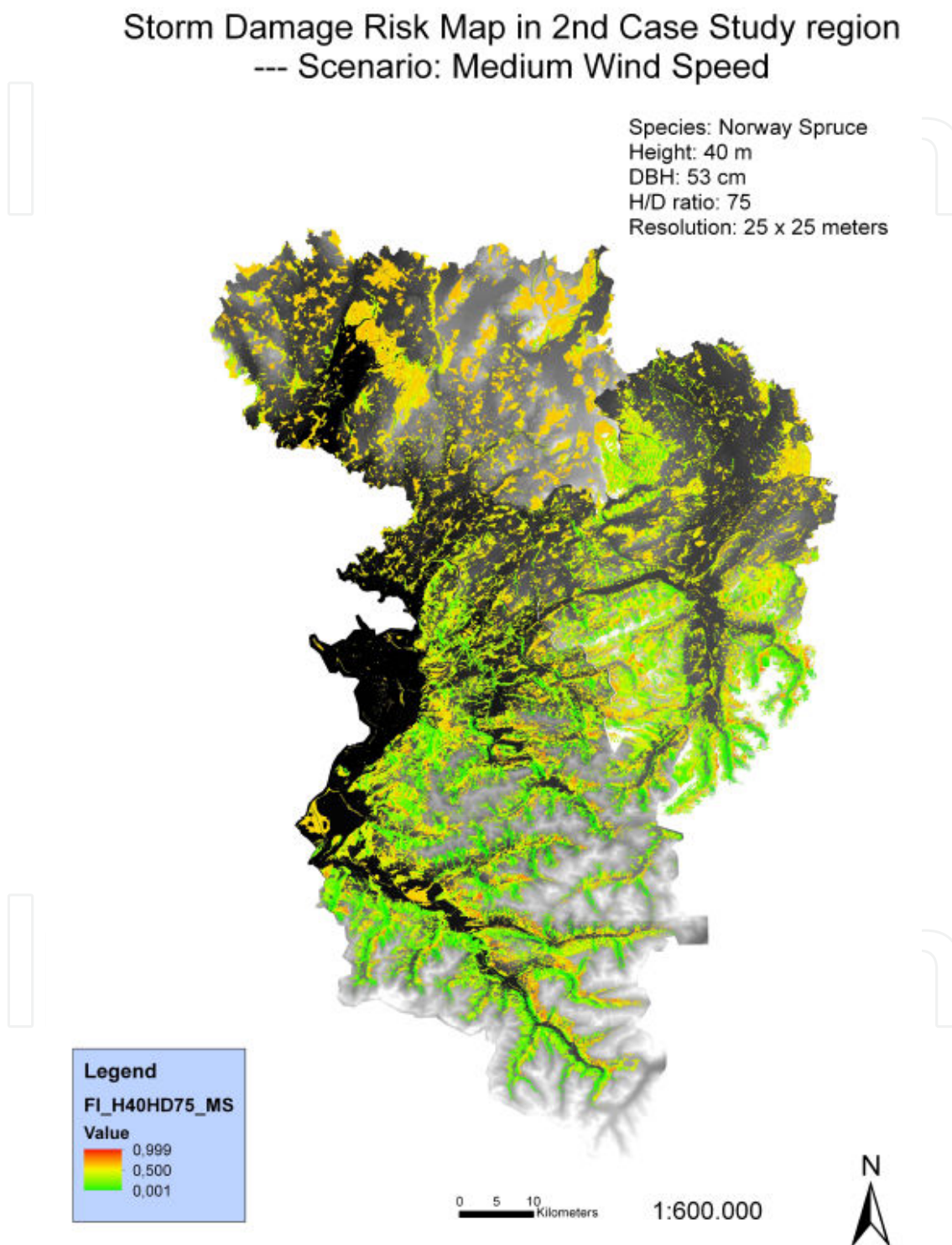


Figure 10. Storm damage probability under moderate wind speed scenario

5. Management strategies and policy recommendations to cope with storm damages

Over the period 1950 – 2000 storms were responsible for 53 % of total damages in European forests [9]. Because storms have a high potential to cause severe economic and ecological consequences in forests[15] it is important to minimize the damages as much as possible. In one of previous chapters it is discussed that many factors (climate, wind speed, topography, soil condition, forest structure) are important triggers for storm damages in forests. On most of those factors humans have no direct influence, but with appropriate silvicultural and forest management decisions it is possible for humans to control the structure of forest.

To minimize the forest damages produced by storms it is important to discuss two questions, first how to improve the resistance of forests to strong winds (PREVENTION) and second how to proceed if severe storm damage in forest happens (POST-STORM MANAGE STRATEGIES).

Review of most important actions to prevent storm damages in forests:

- Natural tree species composition is more resistant to storm damages than exchanged tree species composition [27].
- Conifers are more vulnerable than deciduous or mixed forests. Spruce and silver fir are the most and least vulnerable coniferous and poplar and oak for the broadleaves [2].
- Appropriate mixture of tree species reduces storm vulnerability of forest. Even a mixture of 10 % of broadleaved trees or wind-firm conifers (silver fir or larch) is very effective [16].
- Vertical forest composition plays an important role in stability of forest against strong winds. Unevenly-aged forests and selection forests are more resistant to storm damages than evenly-aged forests [28,29, 29].
- With increasing tree height also damage probability increases [13].
- With decreasing tapering or increasing height/DBH ratio increase storm damage probability [30].
- Susceptibility of a stand to wind damage increases with large mean diameter and with higher stand age [19] or overmature stands [31]. All of this indicates that leaving stands past the normal rotation age involves greater risk.
- Thinning is also an effective measure for improving stability of the stand, but it must be done soon enough. The key to effective thinning is to enhance stability factors (stem, form or crown) without loosening stand cohesion [16].

Despite appropriate use and implementation of reviewed preventive measures, it is not always possible to avoid storm damages in the forests. In cases of disasters it is therefore necessary to ensure rapid and coordinated sanitation of the damaged forests. Successful post-storm management requires participation of different disciplines from federal authorities to forestry actors. From this point of view good preparations on those events are essential and to achieve

this regional or country risk management systems should be established. Improvements in the following areas should be done [32]:

- Optimal management of the crisis
- Organization of the labour force and equipment
- Selection of appropriate techniques and methods
- Implementation of logistics
- Determination of the financial requirements

Until time of writing of this text it is already possible to find some guides which aims to help both public institutes and wood-chain professionals to take decisions, prepare their future actions and improve cooperation in the event of hurricanes [33,34]. In the future all EU countries should establish effective post-storm management systems

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