Student thesis series INES nr 345

Developing a model with help of GIS to assess risk for Storm Damage in Kronoberg County

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2015
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Frida Ulfves (2015). *Developing a model with help of GIS to assess risk for Storm Damage in Kronoberg County*
Bachelor degree thesis, 15 credits in Physical Geography and Ecosystem Science
Department of Physical Geography and Ecosystem Science, Lund University

Level: Bachelor of Science (BSc)

Course duration: *January* 2015 until *June* 2015

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Bachelor thesis, 15 credits, in Physical Geography and Ecosystem Science

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Abstract

During the 20th century storm damage in Sweden has increased as a consequence of how the forest has been managed, an increased proportion of forest and older tree stands. The increase of storm damage has consequences for the regional economy, infrastructure, foresters, and the society. At the same time the climate is gradually changing, which means increased temperatures and higher precipitation ranges. Progressively we are shifting towards another climate, and an altered climate will have both direct and indirect effect on our forests.

To prevent future storm damage to our forests it is essential to adapt. Forest management must be scrutinized and assessed, and models to predict and evaluate storm damage can be valuable. This study focuses on identifying areas with particular risk for storm damage. By doing this it becomes easier to prevent further damage in the future. It facilitates the decisions for foresters regarding management strategies but also makes it possible to perform deeper assessments of influencing factors, both abiotic and biotic. In this thesis the landscape of Kronoberg County, a county in southern Sweden is examined. Several variables are applied to a classification model which demonstrates five categories of varying risk of storm damage. The model was then compared to actual storm damage to investigate its accuracy.

The study showed that when it comes to storm damage to forests this type of simple classification modelling gives a rather realistic picture of the forest sensitivity. A flat landscape like the county of Kronoberg made it easier to perform the analysis since topography can have a large impact on the extent of storm damage. Changing values and altering weighting in the equations was an effective way of investigating the best type of model design. Kronoberg County it is essential to encourage the establishment of mixed forest stands at a rejuvenation stage.

Key words: *Storm damage, wind throw, classification modelling, climate change, forest management*

Sammanfattning

Under 1900-talet har stormskador på skog ökat vilket är en konsekvens av vårt skogsbruk, en ökad volym av skog, och äldre skogsbestånd. Denna ökning av stormskador har konsekvenser för ekonomi, infrastruktur, skogsägare och samhälle. Samtidigt ändras klimatet successivt, och detta kommer i framtiden att innebära högre temperaturer och ökad nederbörd. Långsamt närmar vi oss ett nytt slags klimat, som kommer att ha både direkt och indirekt påverkan på våra skogar, men med förändrat skogstillstånd som följd.

För att motverka framtida stormskador på skog är det viktigt med anpassning. Skogsbruket måste granskas och bli bedömt och modeller som förutspår och utvärderar stormskador kan vara betydelsefulla. Den här studien fokuserar på att identifiera områden med särskild risk för stormskada. Genom att göra detta blir det lättare att förhindra stormskada i framtiden. Det hjälper skogsägare att ta beslut gällande metoder för skogsbruk men det gör det även möjligt att genomföra djupare utvärderingar kring de abiotiska och biotiska faktorerna. I den här studien är Kronoberg län, ett län i södra Sverige granskat. Ett antal variabler är applicerade till en klassificeringsmodell, med vilken fem olika kategorier med varierande risk för stormskador kan kartläggas. Därefter är modellen jämförd med faktiska stormskador för att undersöka kvalitén av modellen.

Studien visar att när det kommer till stormskador på skog så ger den här typen av enkelt klassificeringsmodellerande en någorlunda realistisk bild över skogens känslighet. Topografin har ett betydande inflytande på omfattningen av stormskador och analysen förenklades något på grund av Kronobergs flacka landskap. Att ändra värden och byta ut viktningar i ekvationerna var ett effektivt sätt att undersöka bästa modellutformning. Modellresultaten indikerar att för att kunna motverka framtida stormskador i Kronoberg är det essentiellt att vid föryngring se till att gynna uppkomsten av blandbestånd.

Nyckelord: *Stormskada, vindfällning, klassificeringsmodellering, klimatförändringar, skogsbruk*

Acknowledgements

First I would like to thank my supervisor Anna Maria Jönsson for support and guidance during this thesis. I also want to thank Liselott Nilsson, Svante Claesson and Anders Persson from Skogsstyrelsen (The Swedish Forest Agency) for helping me with data and making this thesis possible.

Contents

1. Introduction

In the last century the volume of storm damage in Swedish forests has increased (Nilsson et al. 2004). The storms causing the most severe damage occurred during the years 1954, 1967, 1969, 1999, 2005 and 2007. The cause behind the increase has been largely discussed. One suggestion is that it can be explained by the steadily increasing amounts of forest being planted (Nilsson 2008; Schelhaas et al. 2003) These forests are commonly made of spruce (*Picea Abies*), which is well known for being highly susceptible to storms (Schütz et al. 2006; Nilsson 2008). Some people may believe that the increased damage is because wind climate has changed, but this explanation is rather unlikely. Studies conclude that the Swedish wind climate has remained unchanged during the last decade and can therefore not be a reason behind the increasing trend in storm damage (Nilsson 2008). Storms have neither increased in frequency nor in strength, but a concern with respect to storm damage is the probability of a changed future climate. Simulations have been conducted on the forest vulnerability to wind with the current forest management in northern and southern Sweden, demonstrating that the indirect effects of a changed climate would possibly make the forests more sensitive to strong winds (Blennow et al. 2010). The effects of a changed climate will result in changed soil composition, lower tree vitality, droughts and shorter time of frozen ground (Schlyter et al. 2006). Likewise, intensified winds would also enhance the effects of damage to forests, even though according to IPCC a windier climate is not to be expected in the nearest future (Field 2012).

When assessing storm damage to forests several factors have to be considered. There are both abiotic and biotic factors regulating the severity of storm damage. The abiotic factors include wind, topography and soil conditions. The topography and the geographical setting such as aspect, slope and altitude are deemed to be strongly connected to storm damage (Everham and Brokaw 1996). Wind is the main triggering factor and the degree of impact depends on the timing of the event, duration, and the behaviour of the wind (Fridman 2006). Biotic factors controlling the effect of storm on forests are stem size, tree species, and stand characteristics (canopy structure and density). Remaining forest after a storm event is more predisposed due to root damage. An evaluation of previous storm events in the area of interest could be valuable for further analysis.

This thesis focuses on the county of Kronoberg, which is the county in Sweden that is experiencing the most damage to forest caused by storms in the last century (Nilsson 2008). Kronoberg contains great amounts of forest which has a strong cultural value in the area. The forest productivity potential is high and the yearly felling stands for approximately 9 billion SEK. The forested areas are more than 80 % privately owned (Skogsstyrelsen 2015b). Historically, Kronoberg has experienced several storm events, although one storm which the majority of the people in the county unquestionably remember is Gudrun. It struck the southern part of Sweden in January 2005 and devastated roughly 14 % of the land area in the county (Skogsstyrelsen 2006) To avoid further storm damage to forests and economic losses that may follow, effective methods to evaluate the risk of damage need to be developed. A classification method could be used to identify areas at risk. In this study high risk areas will be identified and also the variation in risk of damage within the landscape will be assessed. This will be done by generating a classification model containing key parameters.

1.1 Aims

This study aims to develop a model with help of Geographic Information System (GIS) to assess and classify the risk for storm damage in Kronoberg County. This will be performed by:

- Applying key variables which have a potential to influence the amount of storm damage and then utilizing existing classification parameters. The emphasis will be put on the abiotic and the biotic factors, although, the forest management will be considered as well.

- Assessing the key variables separately.

The model will be adapted to suit the landscape of Kronoberg County, and the result is expected to give indications on how the risk for storm damage varies in the landscape. To obtain a better understanding of the landscape and the interactions of the abiotic and biotic factors the classification model is compared with damage caused by a previous storm event. To enhance the knowledge regarding forest susceptibility, methods for a sustainable forestry will be discussed with respect to climate change.

2. Background and Theory

This section describes the theoretical aspects regarding storm damage to forests, how key abiotic and biotic factors interactively affect the impact of storm winds in forests. Moreover, a possible future climate is considered and the importance of forest management is explained. Kronoberg County and the historical storm event Gudrun will be presented.

2.1 Mechanics of Storm Damage

The vulnerability of a forest to storm damage is dependent on numerous factors, the characteristics of wind climate, forest structure, the tree and stand properties and the landscape and its topography and edaphic properties. Similarly, the forest management such as thinning, spacing, fertilization and timing of final cutting also can have a large impact (Gardiner et al. 2013).

2.1.1 Tree Species

The selection of tree species has a major influence on the risk of storm damage to forests. This can be explained by the explicit differences in the physical structure of trees. When it comes to the trees in Kronoberg County, Norway spruce is the most frequently planted species (Skogsstyrelsen 2006). Nevertheless, spruce has a very superficial root system which makes it considerably more vulnerable than the sturdier species Scots pine (Gardiner et al. 2000; Schmidt et al. 2010). To increase the resistance of the forest it is suggested to plant deciduous trees together with coniferous trees. Mixed forest stands adapt marginally better to changes in site conditions and are additionally more productive than pure stands. During winter times broad leaved trees lose their leaves and allow coniferous trees to develop denser crowns (Pretzsch and Schütze 2005). Furthermore, an assessment of storm damage in forests conducted by Schütz et al 2006 showed that spruce might be three times more vulnerable to strong winds than beech (Schütz et al. 2006). This great contrast in resilience can be supported by statistics derived after the storm Gudrun. Regarding the proportion of damaged forest species, 50 % spruce was destroyed, followed by 18 % pine and 2 % broadleaved trees (Skogsstyrelsen 2006).

2.1.2 Tree Height and Stem Diameter

The relation between the two physical parameters tree height and stem diameter together controls the critical moment of overturning. Normally, a higher tree has greater diameter and is therefore rather resistant to storms, although this can also depend on how dense the forest is or if the stand has been thinned or not (Gardiner et al. 2000). On the other hand, a larger tree receives more wind loading which subsequently reduces the resistance to some degree (Gardiner et al. 2000). According to a report conducted after the storm “Lothar” in Germany 1999 tree height was the most critical factor to the degree of damage. This study also brings up the calculation of slenderness ratio (which was used in this study) which is an indicator of the trees stability. The calculation uses the stand dimension, which means tree height divided by the diameter at breast height (Cucchi et al. 2005).

2.1.3 Spacing and Thinning

Plant spacing has various effects on the forest growth and development. Applying generous spacing generally results in larger tree diameter and higher stability of the individual trees. However, when it comes to the timber quality, a dense stand could be more desirable. Closer spacing has an effect of earlier canopy closure and natural self-pruning for the valuable parts of the stem. The drawback is that the stability of the individual tree may potentially be reduced, which enhances the risk of wind throw (Gardiner et al. 2013). When a forest stand is thinned the space between the trees will be increased, and resulting in lower stability of the remaining trees, which also means a lower social stability. The timing after thinning of a stand is always critical, as it takes at least a few years for a forest to acclimatize to the new conditions. If by chance a storm strikes during this time the damages would very likely be more severe than if it would occur before the thinning (Gardiner et al. 2013). A study performed in the area of southern Sweden (Götaland) verifies that by increasing the amount of deciduous trees after a pre-commercial or early thinning will reduce the risk of wind damage during the winter (Valinger and Fridman 2011). Reports suggest that there might be advantages with the procedure of thinning. Nevertheless, the question whether to perform thinning or not is rather dependent on the soil conditions, if thinning is applied on dry soils the effect may give a positive effect on the roots. The roots would grow stronger and hence give a much more stable stand. However, if thinning is carried out on wet soils there is a risk that root anchorage permanently lose its strength and actually decrease in size (Skogsstyrelsen 2006).

2.1.4 Terrain and Soil

Tree stands located at an aspect facing the wind direction might experience a doubled risk for storm damage. Steeper slopes on the other hand reduces the vulnerability to a large extent (Schütz et al. 2006). When the slopes are more gentle (less than 6 degrees) the vulnerability may on the other hand be enhanced. A report carried out after the storm Anatol in Skåne County showed that 59 % of the damaged forest was distributed on gentle slopes facing the South to Southwest direction. The winds during this storm event were generally coming from the west. (Nilsson et al. 2007). The depth of the soil may positively affect the degree of damage. If the soil layer is shallow the root cannot develop (Anon. 1998) and a study carried out in Finland showed that a reasonable number of trees distributed in this type of soils where damaged (Zubizarreta-Gerendiain et al. 2012). The depth of the soil does however not necessarily influence the extent of storm damage, and an analysis of the September storm in 1969 showed no significant effect of soil depth (Fridh 2006).

2.3 Adaption Strategies to Lower the Risk of Storm Damage

The climate is progressively shifting towards warmer temperatures and the forestry is facing the challenge of adapting to climate change. Currently, both the proportion of coniferous trees and the coniferous growing stock is increasing. This is a concern due to the high susceptibility of spruce. Essentially, new strategies need to be introduced to counteract the alarming trend of storm damage (Schelhaas et al. 2003). For example, stand structure is a crucial aspect, and if there would be a procedure to improve this it would probably benefit the forest. However, there are several ways to manage the forest in a way that would improve the stand structure and the question of which strategy to apply. A wind-tunnel study performed by Gardiner et al concludes that there is no simple solution regarding optimization that would improve the stand structure and its stability (Gardiner et al. 2005). A rather simple adjustment is to deliberately perform the selection of species, however, it is important to remember that it is strongly related to the soil conditions. Each tree species has its own habitat and interacts accordingly with the environment and the surrounding vegetation. Moreover, the adjacent forest types is typically considered when choosing a species to plant (Albrektson et al. 2012). There are many challenges to overcome regarding adaption strategies. Nonetheless, the Swedish Forest Agency has made an attempt and modelled various future scenarios with respect to management. These are designed to visualize the consequences of possible actions. The outcome showed varying results. The stock of timber is gradually increasing and the trend is visible for all scenarios with respect to forest management. For the distribution of species in the southern Sweden, spruce increases noticeably while the proportion of pine is decreasing (Skogsstyrelsen 2008).

2.4 Study Area – Kronoberg County

Kronoberg County is located in the southern part of Sweden and covers an area of 8,466 km². It borders the counties Kalmar, Blekinge, Skåne, Halland, Västra Götaland and Jönköping (Figure 1). The climate within Kronoberg varies slightly. The areas surrounding the large lakes Åsnen and Möckeln have a rather mild climate with forests predominantly containing deciduous trees. The northern parts have higher elevations and this area is somewhat more barren than the rest of the county. The western part is characterized of relatively flat land and has a quite high rate of yearly precipitation. There are also a high number of mires which are important for the area. The eastern area is considerably drier in comparison to the west. The dominating forest species are spruce, pine and birch, the proportion of each species is spruce 49.8 %, pine 30.6 % and birch 12.3 %. The distribution of the species and the types of forest can be seen in Figure 2. (Skogsstyrelsen 2015a) The precipitation ranges between approximately 1000 mm in the west and about 400 mm in the east (Skogsstyrelsen 2015b) The soils in the county of Kronoberg mainly consist of morain (Lantmäteriet 2015a). This types of soil are evidenced to positively influence the growth of spruce (Johansson 1995).

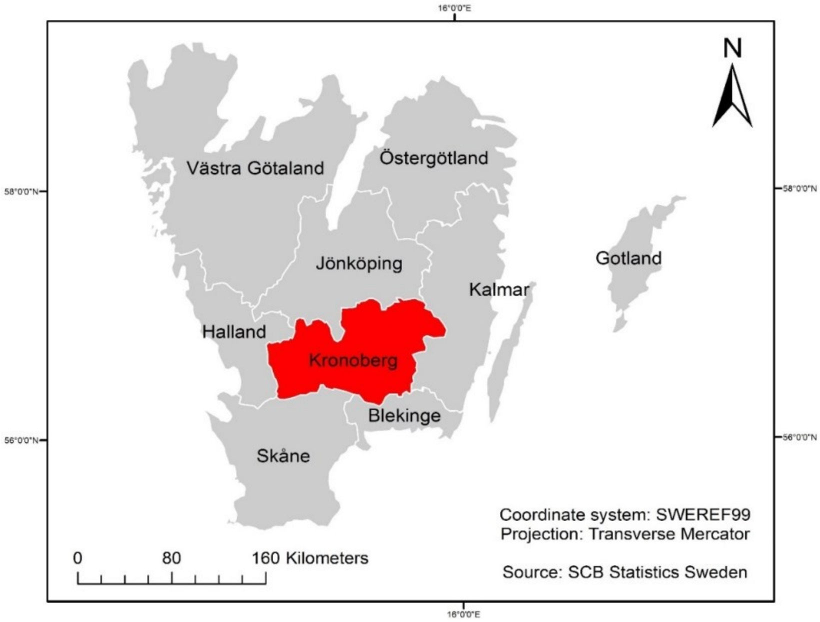

Figure 1. Sweden and county divisions

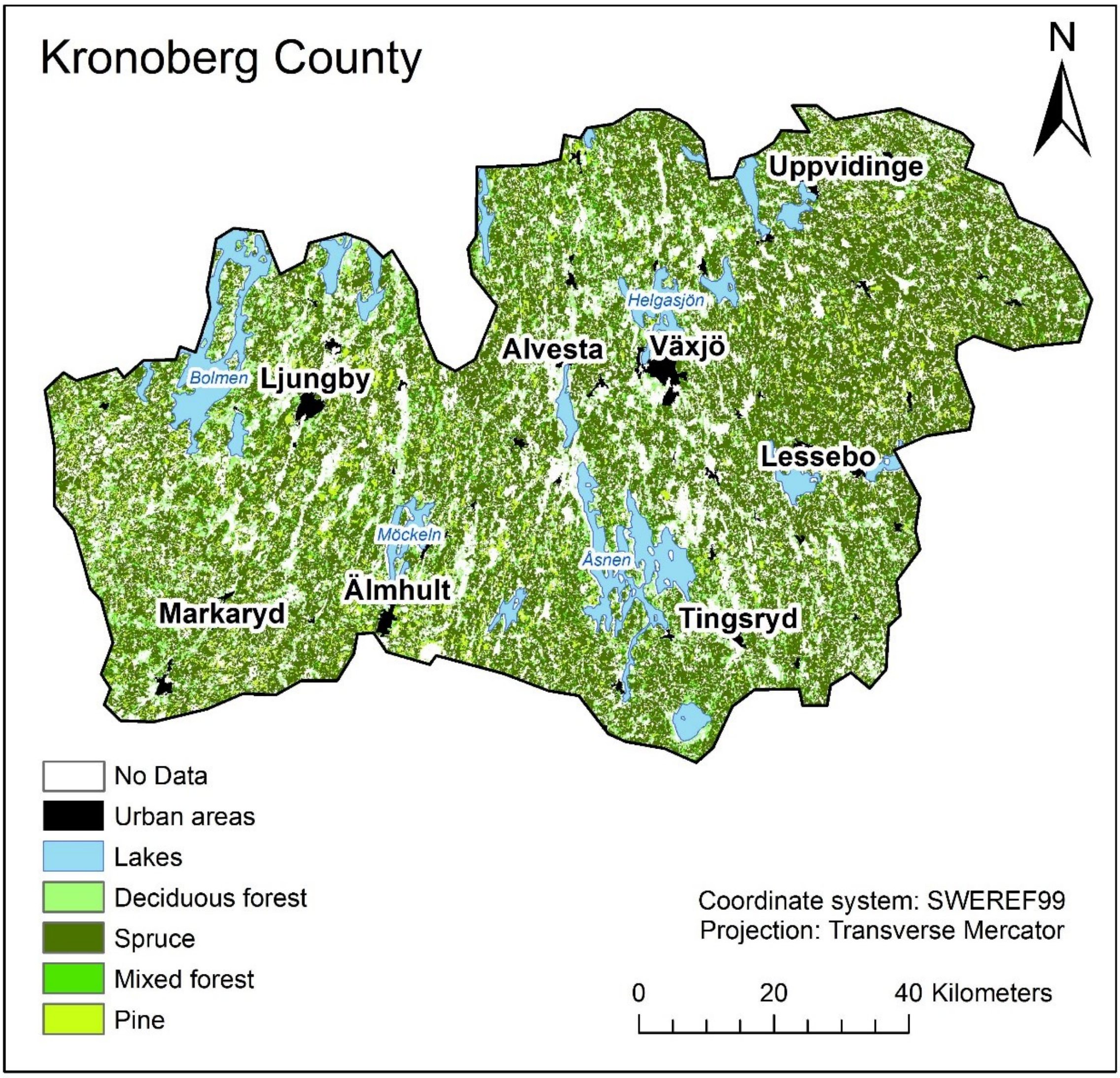

Figure 2. Kronoberg County and the distribution of forest species and forest types. The highest

concentrations of spruce is located around Växjö, Alvesta,Lessebo and Tingsryd. Pine is occurring both in the west and in the east. The proportion of mixed forest is very small.

2.4.1 Effects after the Major Storm Gudrun in Kronoberg County

One storm event which most people in Kronoberg undoubtedly recall is the January storm Gudrun. During a late Friday night on the 8th January 2005 the disastrous storm struck Sweden. Locations with particularly high winds were observed within Kronoberg in Ljungy and Växjö, respectively, where the wind reached up to 33 m/s (Skogsstyrelsen 2006) Kronoberg was affected extensively and large amounts of forest were damaged (Figure 3). There are several estimations regarding the volume of damaged forest, but the Swedish Forest Agency suggests that roughly 75 million m^3 forest was destroyed by the winds (Skogsstyrelsen 2006). An analysis performed by SLU presents a comparison regarding the forest management before and after the storm Gudrun. The investigation confirms that spruce was planted at 85-90% of the area that was affected by the storm. Additionally, no adjustments were made regarding the selection of tree species. Further, the paper verifies that an increase of thinning was visible for a period just before the storm. As a consequence after Gudrun the thinning drastically decreased, although after a few years the thinned forest was back to the same extent again (Kempe et al. 2014). Another report from SLU demonstrates the distribution of forest age within each county and provides a number of the proportion of the total wind thrown forest. Figure 12 in this report manifests that in Kronoberg the age class most severely affected by Gudrun was 81-90 years, stands which can be deemed as old (Skogsstyrelsen 2006). Another effect after Gudrun was bark beetle infestations, predominately by the species *Ips typographus (L.)*. The damages were vast and according to the Swedish forestry 4 % of the standing trees were affected, approximately 5 million cubic meter (m^3) (Bergqvist 2014). Assessments after the storm reveal that the forest primarily being damaged was thinned and in the age-span 21-80 years, the tree species did not show any statistical significant result of affecting the impact of the storm (Valinger et al. 2014).

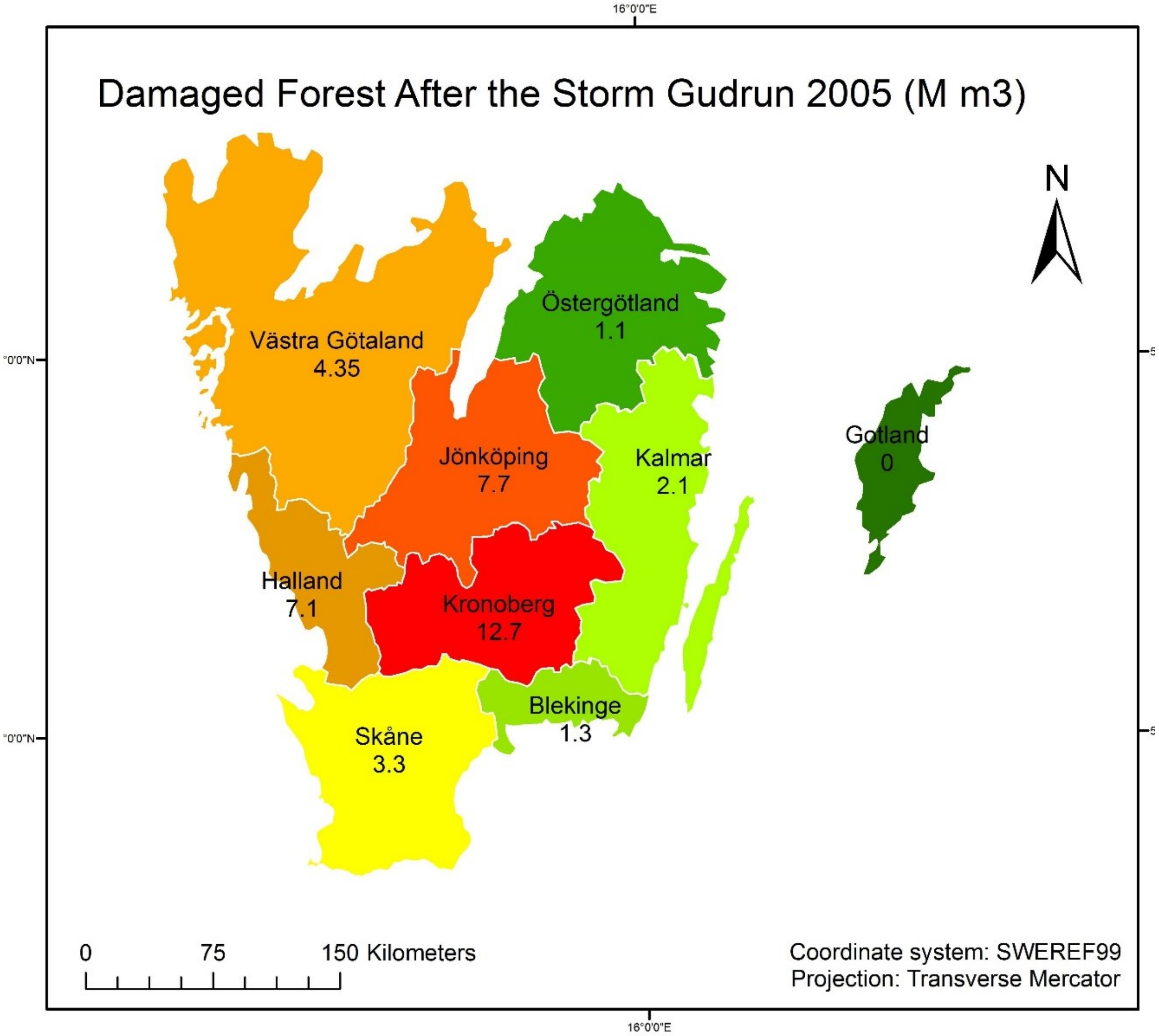

Figure 3. Proportion Storm Damage for each County in Southern Sweden. Kronoberg experienced the greatest volume of damage to forests. The unit m^{3}sk is a measure of forest cubic meter and includes the full tree stem volume.

2.5 Storm Damage Models

Models have been developed to evaluate or predict storm damage to forests, for example, the two mechanistic models GALES and HWIND. These models are designed to predict the critical wind speed and turning moment to uprooting and breakage of coniferous trees. Both models are relatively complex and include calculations such as aerodynamic roughness and zero-displacement of a forest stand. A large number of variables are applied to the calculations; wind speed, snow depth, stand density, crown depth, crown width, wood density and soil type (Gardiner et al. 2000). There are also a few classification models. An example of such a model is the Wind throw Hazard Classification model WHC. This classification model evaluates tree and stand characteristics and the windiness of a site. The model has been widely used by British foresters to identify areas at risk for wind throw (Quine and White 1992). Moreover, IPCC has conducted a report on the topic 'Managing the Risks of Extreme

Events and Disasters to Advance Climate Change Adaption’ (Field 2012). In this report, they conclude that climate extremes are dependent on exposure and vulnerability, and not only on the extremes themselves. The climate extremes are dependent on factors such as anthropogenic climate change and, natural climate variability. To reduce exposure and vulnerability and at the same time increasing resilience to possible negative impacts of climate extremes, the focus should be put on reducing exposure and vulnerability (Field 2012).

3. Material and Methods

This section presents how the classification model was generated and describes how the variables were chosen, manipulated and applied to it. Each step in the process is explained and visualized with equations, figures and tables.

3.1 Data

All GIS calculations were performed in ESRI ArcGIS 10.2.2. Data on topography was obtained from a Digital Elevation Model, DEM, with the spatial resolution 50x50m from Lantmäteriet. The Swedish Land Survey. The resolution was chosen due to excessive amounts of data layers A number of other layers describing spruce, pine and deciduous trees, average tree height, average tree diameter, soil depth etc. were available at Lantmäteriet, but also at the Swedish Forest Agency and SLU, Swedish University of Agricultural Sciences. Details regarding this data can be found in Table 1. The maps were produced in this study by using available data and the diagrams were completed in Microsoft Excel.

Table 1. *Vector and Raster lasers for visualization of maps and the classification model. The data is obtained from SCB Statistics Sweden, The Swedish Land Survey and the Swedish Forest Agency and the Swedish University of Agricultural Sciences SLU. All raster data is harmonized to a resolution of 50x50m. Reference system: SWEREF99 Projection: Transverse Mercator.*

Vector Data	**Modification**	**Explanation**	**Source**
County Boundary	Clip to county boundary	Kronoberg county's Administrative boundary	SCB Statistics Sweden
Waterbodies	Extracted from the soil type data	Lakes in the study area	The Swedish Land Survey
Urban areas	None	Cities and towns in the study area	The Swedish Land Survey
Marshland	Converted from vector to raster, extraction of "pine dominates", overwritten to the land use layer containing forest types	Marshland with areas containing "pine dominates"	The Swedish Forest Agency
Soil depth	Inverse Distance Weighted (IDW) Interpolation of point layer to create a raster layer	A continuous layer showing the depth of the soil in the study area	The Swedish Land Survey

Table 1, cont.

Raster Data	**Modification**	**Explanation**	**Source**
Digital Elevation Model	None	Elevation model covering Kronoberg County, 50x50 m resolution	The Swedish Land Survey
Average Tree Diameter	Merging of raster layers and clip to county boundary, converted to decimetre (dm), used to calculate Slenderness ratio	Data from laser scanning, 2014, originally 12.5x12.5m resolution, diameter in (cm)	The Swedish Forest Agency
Average Tree Height	Merging of raster layers and clip to county boundary, used to calculate Slenderness ratio	Data from laser scanning, 2014, originally 12.5x12.5m resolution, height in decimetre (dm)	The Swedish Forest Agency
Land use	Clip to county boundary, extraction of coniferous forest, deciduous forest and mixed forest	Areas covered by coniferous forest, deciduous forest and mixed forest within the study area, originally 25x25m resolution	The Swedish Land Survey
Pine	Clip to county boundary, project raster (RT90_2_5_gon_V to SWEREF99)	The distribution and volume of Pine in the study area (m^3 sk/ha), original resolution: 25x25m	SLU, Swedish University of Agricultural Sciences
Spruce	Clip to county boundary, project raster (RT90_2_5_gon_V to SWEREF99)	The distribution and volume of Spruce in the study area (m^3 sk/ha), original resolution: 25x25m	SLU, Swedish University of Agricultural Sciences
Deciduous forest	Clip to county boundary, project raster (RT90_2_5_gon_V to SWEREF99)	The distribution and volume of Deciduous forest in the study area (m^3 sk/ha), original resolution: 25x25m	SLU, Swedish University of Agricultural Sciences
Damaged forest	Reclassify (0-undamged, 1-damaged)	The distribution of damaged forest after the storm Gudrun, original resolution: 10x10m	The Swedish Forest Agency
Soil moisture	Merging of raster	The distribution of	The Swedish Forest

	layers and clip to county boundary	soil moisture in the landscape of Kronoberg, original resolution: 2x2m	Agency

3.2 Classification Modeling and Parameterization

For the classification model GIS data was applied to facilitate the estimation of varying risk for storm damage in Kronoberg. The variables were chosen to be the following: Tree species, elevation, tree height, tree diameter, soil depth, aspect and general wind direction. The variables were chosen with respect to available data and depending on what earlier studies claim about factors having an impact on storm damage. The classification indices for soil depth were obtained from the Wind hazard classification model WHC, a model which is extensively used by British foresters to localize areas at threat of storm damage (Quine and White 1992). The Topographic exposure is also mentioned in the Wind Hazard Classification WHC, however, the actual calculation was obtained from Mikita and Klimánek (Mikita and Klimánek 2010). The equation for slenderness ratio was taken from Becquey and Riou-Nivert (Becquey and Riou-Nivert 1987). The classification model consists of two parts, the first one as a multiplicative equation weighting the tree species together and the second part as an additive equation, adding the landscape and the topography characteristics (Topographic exposure, soil depth and aspect) together with the tree characteristics (Slenderness ratio). Lastly, the two resulting layers were multiplied together to obtain the final score, which the risk for storm damage was classified into five categories (low, moderate low, medium, moderate high, and high). The entire model was run in ArcGIS and the workflow can be seen in Figure 4.

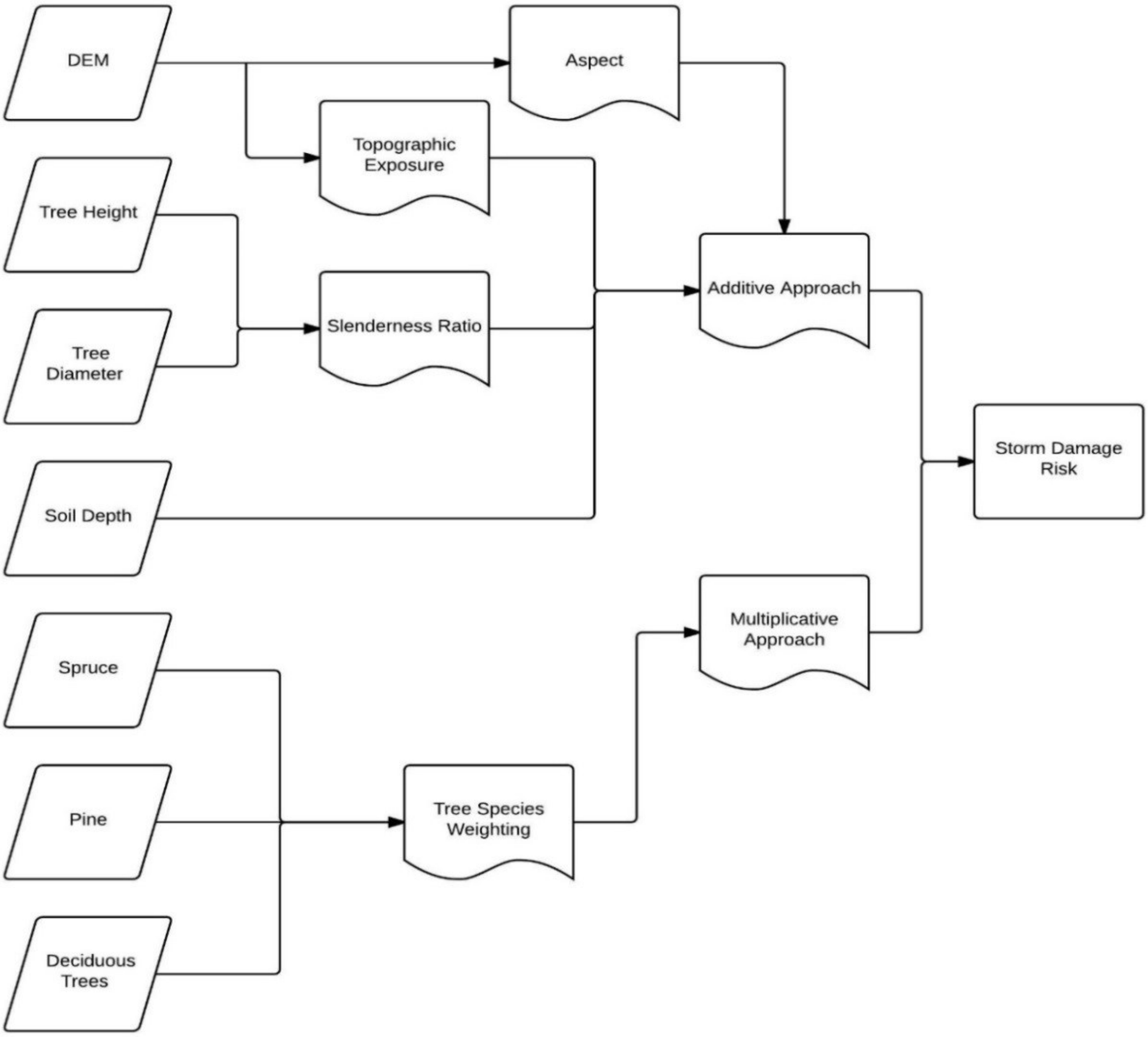

Figure 4. Flowchart describing the modelling work process.

3.2.1 Multiplicative Approach

The tree species spruce and pine and deciduous trees (data from SLU, Swedish University of Agricultural Sciences) were weighted together with a specific constant, which will be described and explained in the following chapter.

3.2.1.1 Tree Species

This study focuses on the species composition and a great number of studies support the idea of tree species having a large influence on the degree of storm damage (Schütz et al. 2006) Also the majority of studies agree that spruce is the most vulnerable tree species (Valinger and Fridman 2011; Schütz et al. 2006).

3.2.1.2 Weighting

With respect to what previous studies claim and the fact that Kronoberg contains a large proportion of spruce, the species received a ‘species constant’ to weigh it with the rest of the variables. The species constant used for this model was developed by Valinger and Fridman and the values were set to 1.0 for spruce, 0.5 for pine, and 0.1 for the deciduous trees (Valinger and Fridman 1999). Pine received a somewhat lower value than spruce due to its slightly higher resilience (Gardiner et al. 2000; Schmidt et al. 2010). Deciduous trees obtained the lowest value (lowest impact) because those trees have the lowest susceptibility to storm damage, especially during winter when the majority of storms occur (Gardiner et al. 2000). When performing the weighting a higher value signifies a higher susceptibility due to a larger proportion of spruce. Hence, a lower value indicates a larger proportion of deciduous trees and therefore a lower risk. In ArcMap the three layers of each category were multiplied together. Each layer in the equation represents the volume of the tree species measured in the unit m^3. The equation explains that for monocultures (containing one type of tree species) only one of the categories obtains a value, whereas for a mixed forest stand the storm sensitivity was weighted with respect to the forest stand’s species composition.

For the multiplicative approach the equation is as follows:

$$Equation\ 1\text{:}\ \frac{(Spruce \times 1) + (Pine \times 0.5) + (Deciduous\ trees \times 0.1)}{(Spruce + Pine + Deciduous\ trees)}$$

3.2.2 Additive approach

The additive approach considers the landscape characteristics, the tree traits and a general wind direction, similarly as in the Wind throw Hazard Classification model WHC (Quine and White 1992). The variables comprise elevation, aspect, a general wind direction, soil depth, exposure, tree height, and tree diameter. The equations Topographic exposure (Topex) (3.2.2.2) and Slenderness ratio (3.2.2.3) were used to calculate the exposure at a specific location and the tree stability. After performing these calculations each variable obtained a specific classification score which can be observed in Table 2. The layers could then be added together as specified by Equation 2.

$$Equation\ 2\text{:}\ Aspect/Wind\ exposure + Topex + Slenderness\ ratio + Soil\ depth$$

Table 2. *In this table each variable for the additive approach is presented with their specific classification score. The higher score, the higher impact on the risk of storm damage. Scores for soil depth are obtained from the Wind throw Hazard Classification model WHC (Quine and White 1992). The ranges for Slenderness ratio are derived from the French Forest Institute Revue Forestière Française (Becquey and Riou-Nivert 1987). All scores except of soil depth are modified in order to suit the model. The scores were modified by giving them a similar index to soil depth. This was done with the reason that the soil depth scoring was supported by statistical tests (Quine and White 1992). The scoring does not take the relative importance into account.*

Parameter	Range	Description	Classification score
Topex		The higher values the more exposed	4, 5, 6, 7, 8
Slenderness ratio	< 80	Wind firm	0
	80 > < 100	Somewhat unstable	5
	> 100	Unstable	10
Soil depth	> 45 cm	Unrestricted rooting in excess of 45 cm	0
	25 cm - 45 cm	Restricted rooting but some structural root penetration in excess of 25 cm	5
	0 - 25 cm	Very restricted rooting	10
Aspect/Wind exposure	N, NE, E, SE, S		0
	NW		5
	SW		5
	W		10

3.2.2.1 Wind exposure/Aspect

Wind exposure at a certain aspect can have a high impact on the vulnerability to storm damage (Fridh 2006; Schütz et al. 2006). In Kronoberg the general winds are predominantly coming from West (Wern and Bärring 2009). Trees facing this direction can therefore have a higher risk of wind throw. To implement the wind exposure/aspect to the model, the elevation data was used to calculate aspect (The direction in which a slope faces). The slopes where then divided into the eight cardinal angles (N, NE, E, SE, S, SW, W, NW). Thereafter, these were reclassified, westerly winds received the highest score, and the south-westerly and north-westerly winds obtained a somewhat lower score, the remaining directions received no score at all (no impact). The data for the general winds were collected from the Swedish Meteorological and Hydrological Institute and was an approximation of wind direction during a time period of 18 years (Wern and Bärring 2009).

3.2.2.2 Topographic Exposure

Topographic exposure explains if a specific site is exposed or protected by the surrounding landscape and it is based on relative height and distance to the surrounding horizon. In the exposure calculation the vegetation in the landscape is not taken into the account. The calculation of Topographic exposure was done in ArcMap by shading the elevation model with a hypothetical light source representing the wind direction. When executing this every pixel was comprised and the outcome gave a ranging value indicating the proportion of brightness. The more exposed parts of the landscape are indicated by higher pixel specific values. Regarding parameterization the horizontal angel of the direction of the illumination had to be established. Azimuth corresponded to the north and the vertical angle was derived from the horizontal plane. The default value for a standard procedure of a shaded DEM is 315 degrees for the horizontal plane (corresponding to the direction Northwest) (ESRI 2011). Although, in this model the eight cardinal angles were considered and the values had to be assigned accordingly (N, NE, E, SE, S, SW, W, NW). The default value for the vertical angle is 45 degrees, but for the purpose of this study the value was recommended to be set to five degrees (Boose et al. 1994). The algorithm of illuminating the elevation model is called Hillshade and has the formula:

$$Equation\ 3: Hillshade = 255 \times ((\cos Z \times \cos S) + (\sin Z \times \sin S \times \cos(Az - As)))$$

Z is the zenithal angle in radians, S is the slope gradient in radians, Az is the azimuth in radians and As is the slope exposure in radians. When performing the Hillshade function only one given direction is considered. Therefore, the equation was repeated eight times, including the eight cardinal angles as mentioned previously. After performing the Hillshade function eight layers were created. These layers were reclassified in to two categories (0-unexposed, 1-exposed). After this step the new layers were summarized to a final Topographic exposure map. High values indicate that the location is exposed. A value of eight implies that the location is exposed in each cardinal angle (Mikita and Klimánek 2010).

3.2.2.3 Slenderness Ratio

In a great number of studies it has been concluded that the tree height is a significant factor controlling the extent of storm damage. Higher trees are considerably more vulnerable than shorter trees (Valinger and Fridman 2011). Also the stem diameter has a significant role. A thicker tree has a greater resistance to uprooting and breakage (Peltola et al. 1999). To integrate the tree height and the tree diameter respectively, it was decided to utilize the tree stability tool Slenderness ratio (Becquey and Riou-Nivert 1987). This equation is developed to assist forestry estimating the stem's resilience to wind throw. The tool is easy to use and describes the tree stability. The calculation is basically tree height divided by the diameter at breast height (DBH). The relationship can be seen in Equation 4.

$$Equation\ 4. Slenderness\ ratio = \frac{Tree\ height}{Tree\ diameter\ at\ breast\ height\ (DBH)}$$

When calculating Slenderness ratio the trees are considered to be wind firm at the ratio <80, somewhat unstable <100, and unstable >100 (Becquey and Riou-Nivert 1987). The calculation was performed in ArcGIS and the two layers contained information on a pixel level. Each pixel had an averaged value measured in decimetre.

3.2.2.4 Soil Depth

The soil depth is crucial when it comes to the degree of root anchorage. If the soil is shallow the roots are restricted and cannot fully develop. Due to the limitations of root growth the tree's susceptibility increases potentially, which also means increased risk for wind throw (Anon. 1998). The soil data obtained from the Swedish Forest Agency was divided into three categories. First, the low risk class which comprised a soil layer deeper than 45 centimetres. In this category the roots have generous space and thus an unrestricted rooting. For the second category the rooting is somewhat restricted, but can penetrate to a maximum depth of 45 centimetres. In the last category, (the high risk class), the roots are greatly restricted and can merely reach to a depth of 25 centimetres. The soil depth data from the Swedish Land Survey contained a point layer. To enable the later calculations the point layer had to be converted into a continuous raster. This was done by performing an Inverse Distance Weighted Interpolation (IDW). The IDW predicts unknown locations by using the measured points in the surrounding. This method assumes that near things are more alike than those further away. Hence, the points nearest to the unknown locations have the highest impact. IDW also assumes that the surface being modelled has a local variation. The soil depth data had both local variation and a well and high distributed number of points, therefore, the method of IDW was chosen. After the performance of IDW the data was reclassified according to the previously stated classes.

3.2.2.5 Soil moisture

For further evaluation topographic exposure was excluded from the equation and instead the variable of soil moisture was applied. The data was received from the Swedish Land Survey and was produced by a mathematical model. This model is based on topography (slope and aspect) and was performed to find out the course of the water stream. The areas achieving the criteria with 1 ha catchment were kept and created a flow channel or stream. The data may include some errors. The errors can be found especially at areas with well drained soils where water easily penetrates, and also at manmade features such as ditches. Soil moisture was chosen because it was rarely found in earlier studies. Although, one study which takes soil moisture in consideration is a study performed in Germany after the storm Lothar. The study demonstrates that soil moisture has an impact to the degree of storm damage (Schindler et al. 2009). For the equation soil moisture was classified in harmonization with the rest of the data. The given scores was 0, 5 and 10, with ten implying on the highest impact.

3.3 Evaluation of model – Comparing Result to Actual Storm Damage Data

To evaluate the accuracy of the model, the model result was compared with actual data from the previous storm Gudrun by using ArcMap. The material was obtained from the Swedish Forest Agency and comprises airborne images taken from a low altitude of 1500m. The images were taken from June to September 2005. To simplify the evaluation of the classification model the data was classified into two classes (0-no damage, 1-damage). Performing a distinction like this might be seen as harsh, however, the values in the original data either had a value of 0, or a value in between 170-225m^3. The result and the distribution of storm damage data from Gudrun can be viewed in Figure 5. When comparing the layer representing the classification model and storm damage data ArcMap was used. By adding the layers together it was possible to determine to which categories the storm damage data fell into. The result is visualized in pie charts. This way of visualizing was deemed to be the most suitable, because the coarse resolution and large scale would make a map problematic to interpret. To enable further development, the storm damage data from Gudrun corresponding to the lowest modelled risk class was localized. This demonstrates where the model might not be accurate, since a "low risk class" should inherently imply low risk. The storm damage from Gudrun should preferable correspond with the modelled "high risk class" (Look at figure 6).
The storm damage data from Gudrun corresponding to the lowest risk class is visualized in Figure 12. The investigation may show that either the model is not accurate enough, or there are uncertainties regarding the collected storm damage data. Lastly, a new variable was introduced to the model (Figure 11). Instead of applying Topographic exposure to the equation, a soil moisture variable was used. This can show if soil moisture is a better measure of the altitude's influence on storm damage.

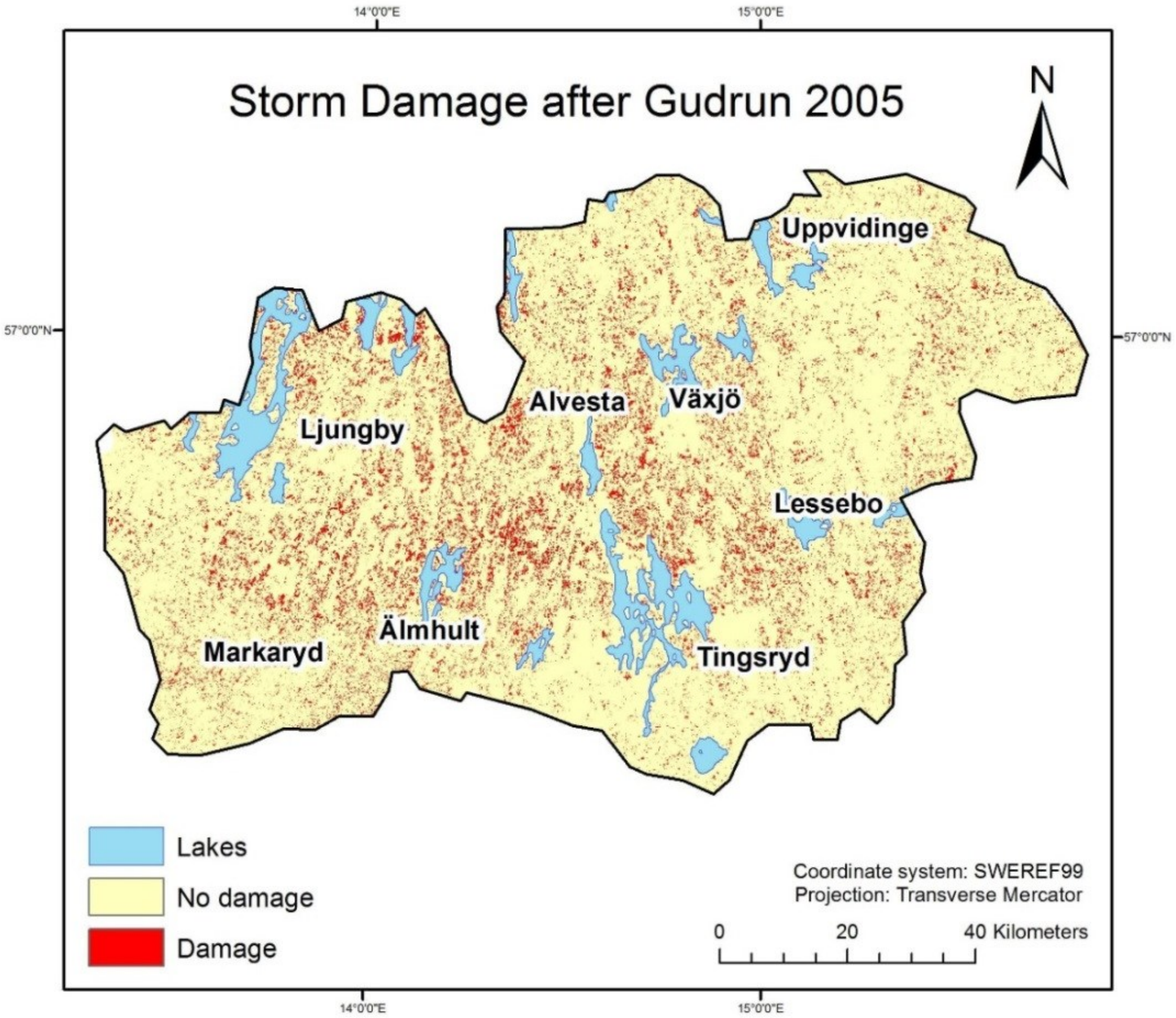

Figure 5. Distribution of damaged forest within Kronoberg County. The Damages are greatest between Älmhult and Växjö. Less damage can be localized around Tingsryd, Lessebo and Uppvidinge.

4. Result

The map demonstrates the outcome of the model showing the forest at risk for storm damage and how it varies within the landscape (Figure 6). The following two maps visualize the result of the multiplicative approach based on Equation 1 and the additive approach based on Equation 2 (Figure 7, Figure 8), along with an evaluation of the model's quality is displayed. The quality assessment was performed by comparing the modelled risk classes with actual storm damage data from Gudrun. The result is presented in pie charts. The first pie chart presents the original idea of the model, and gives an indication on its accuracy (Figure 9). In the second pie chart Equation 1 has been modified by switching the weighting of the variables, giving the highest value the lowest, and the other way around (Figure 10). In the last pie chart the additive approach is adjusted, instead of topographic exposure, soil moisture data has been applied (Figure 11). The last result is another assessment of the original model, showing storm damage data from Gudrun corresponding to the lowest risk class (Figure 12).

4.1 Modelled Risk for Storm Damage

The result of the model displays areas of forest with varying risk for storm damage within Kronoberg. The forests with highest risk are located around Växjö, Tingsryd and Alvesta. The low risk areas can be seen in the east, and the Western area has a moderately low risk for storm damage.

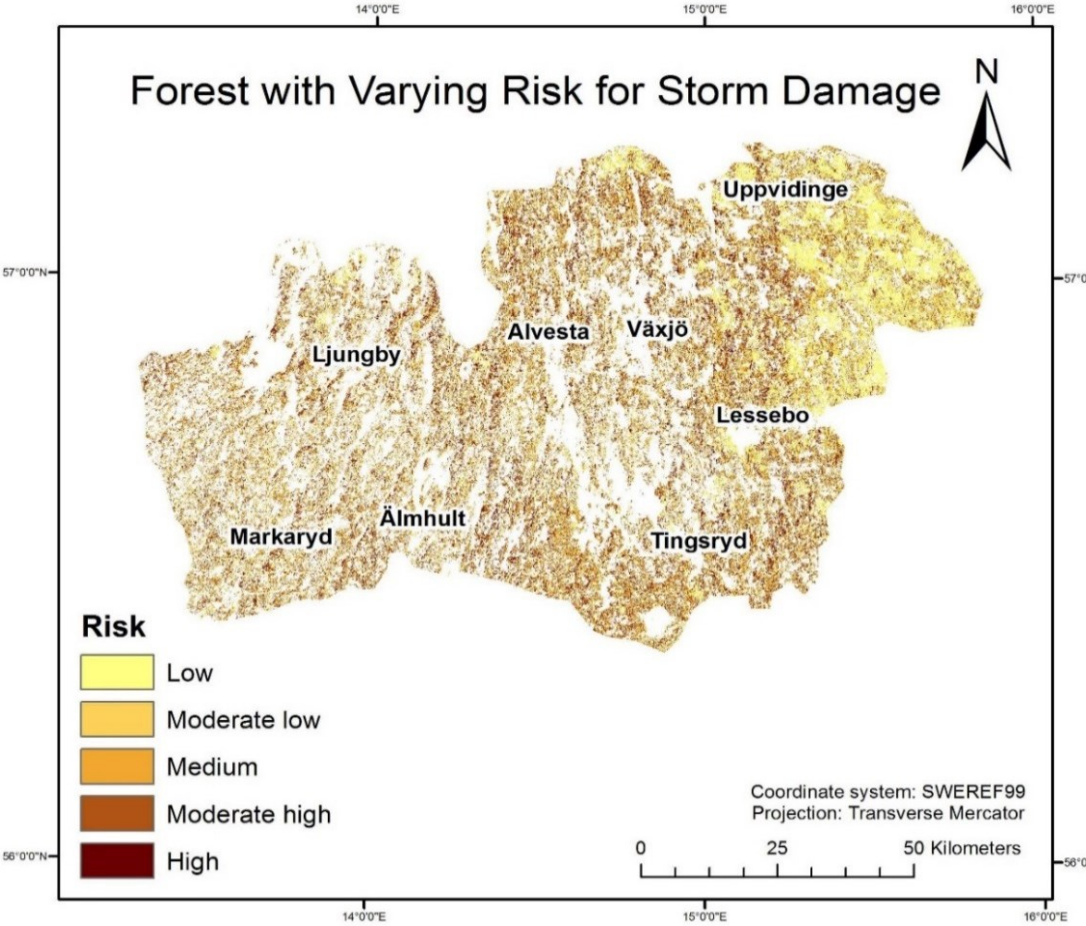

Figure 6. The distribution and the variation of forest with risk for Storm Damage. The area in the east has a somewhat lower risk. The areas around Växjö and Tingsryd have a rather concentrated risk for Storm damage.

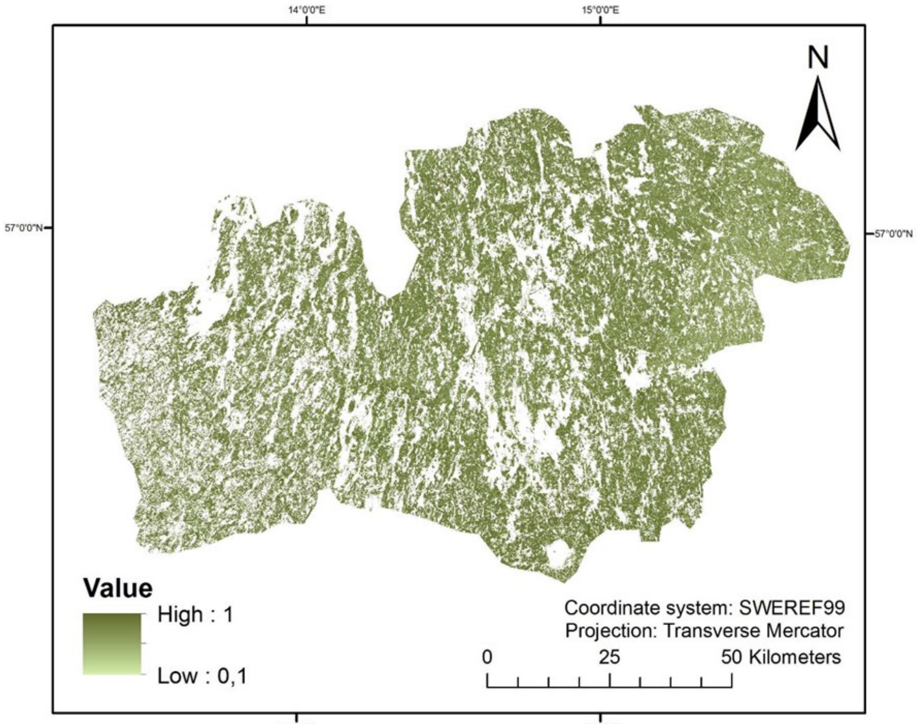

Figure 7. Weighting of tree species. Higher values indicate that there is a high occurrence of Spruce and that the risk is enhanced, this can be seen in the central parts of Kronoberg. The white areas are no data.

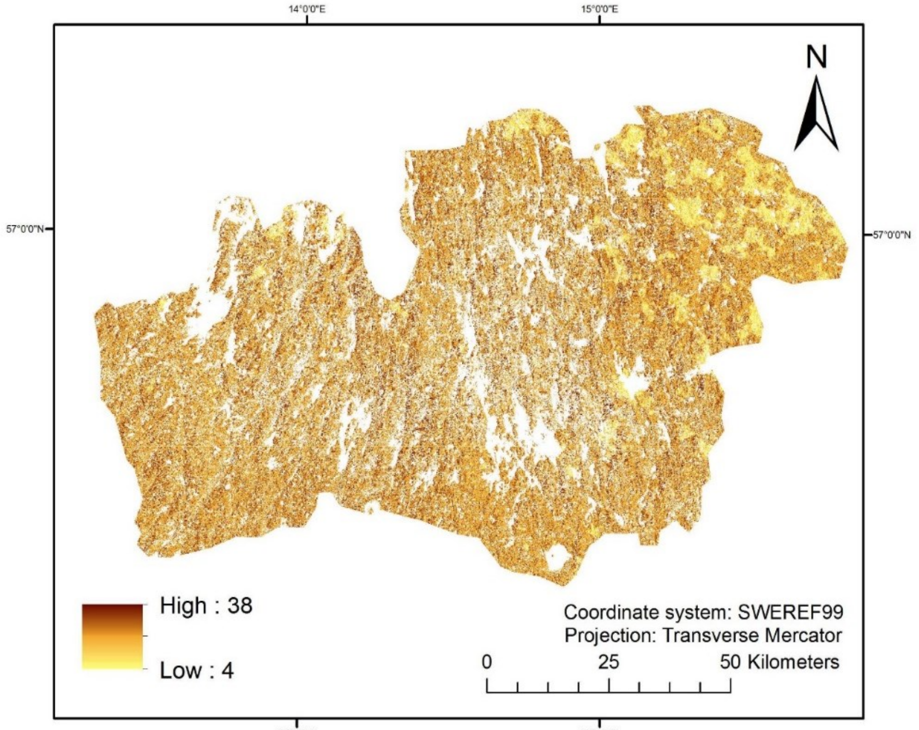

Figure 8. Addition of Topex, Slenderness ratio, soil depth, aspect/wind exposure. The highest values are centrally distributed. The eastern part of Kronoberg has the lowest values. The white areas area no data.

4.2 Modelled risk classes compared with Storm damage data from Gudrun

These result demonstrates how recorded storm damage data from Gudrun correlates with the classification model. Three different model variations were used to investigate the reliability of the model. The first one is performed by simply combining the storm damage data with the classification model. The result makes it possible to distinguish to which categories the storm data fell in to. 56 % of the pixels fell into the categories, high risk, moderate high risk and medium risk (Figure 9). The second model run included a reversed classification of the tree species, i.e. spruce was assigned the lowest weight, and deciduous trees the highest. The result in Figure 10. displays a great contrast to Figure 9. where as much as 92 % of the data fell into the category low damage. The last model run, included the variable soil moisture (Figure 11). This gave the best result with 62 % of the storm damage data corresponding to the highest classes. Figure 12. demonstrates where in the landscape the storm damage data from Gudrun fell into the category low risk.

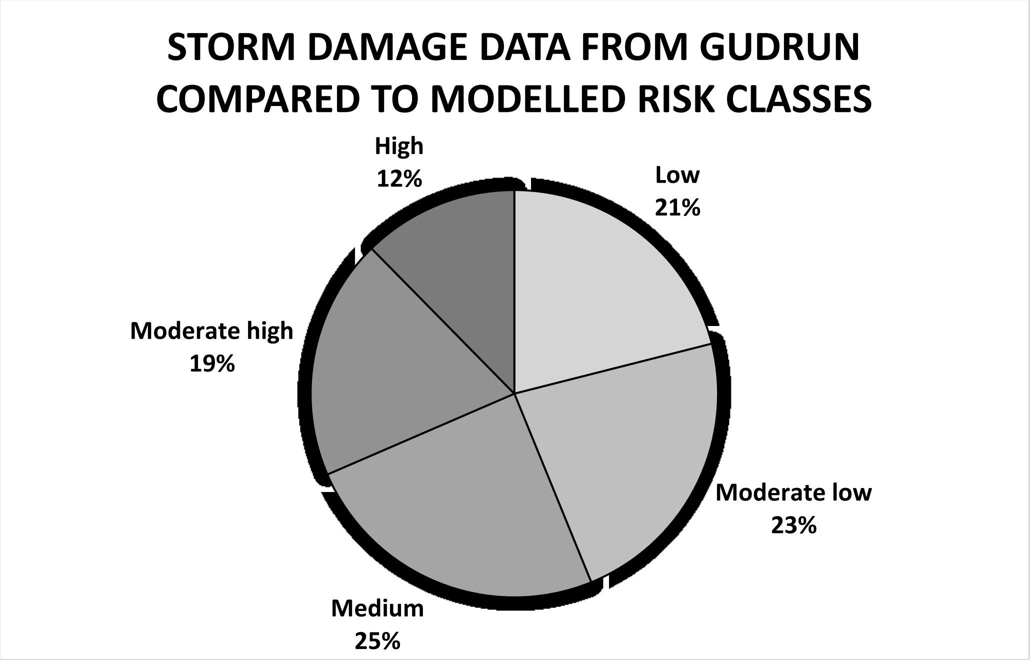

Figure 9. Storm damage data from Gudrun was compared to the model. The storm damage data matching the modelled risk areas fell into the categories according to this diagram. Approximately 60 % of the storm damage data from Gudrun fell into the categories high, moderate high and medium. A great result is when actual storm damage data fall into the category "high", since "high" implies high risk for storm damage.

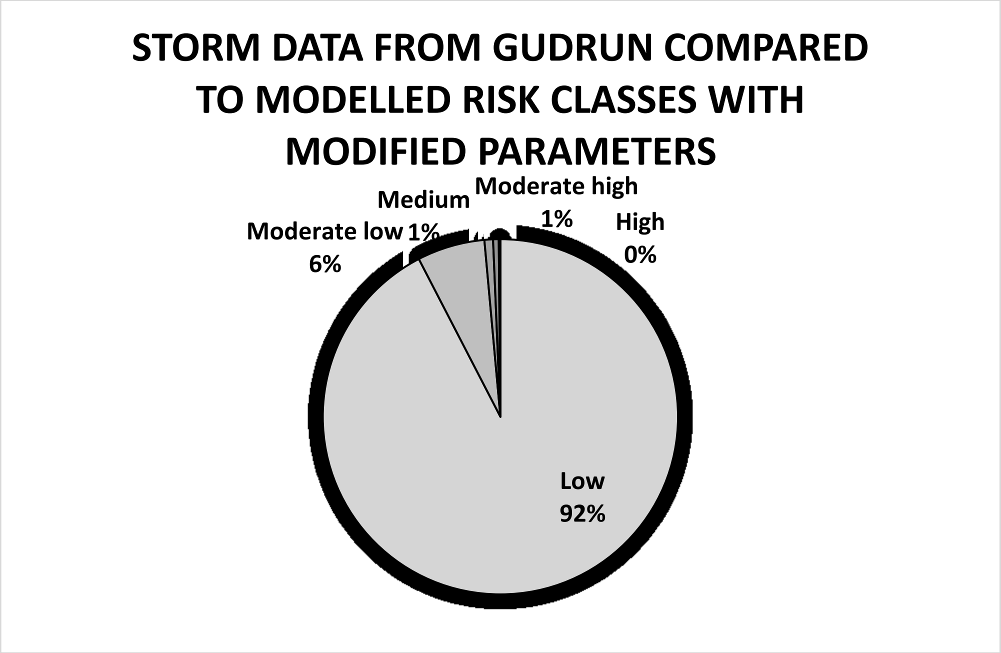

Figure 10. The Diagram shows the consequences of adjusting a parameter in Equation 1. In Equation 1, the highest weight (1.0) was instead assigned to deciduous trees and Spruce obtained the value of least impact (0.1). The Storm Data corresponding to the modelled risk classes fell almost entirely into the category "low risk".

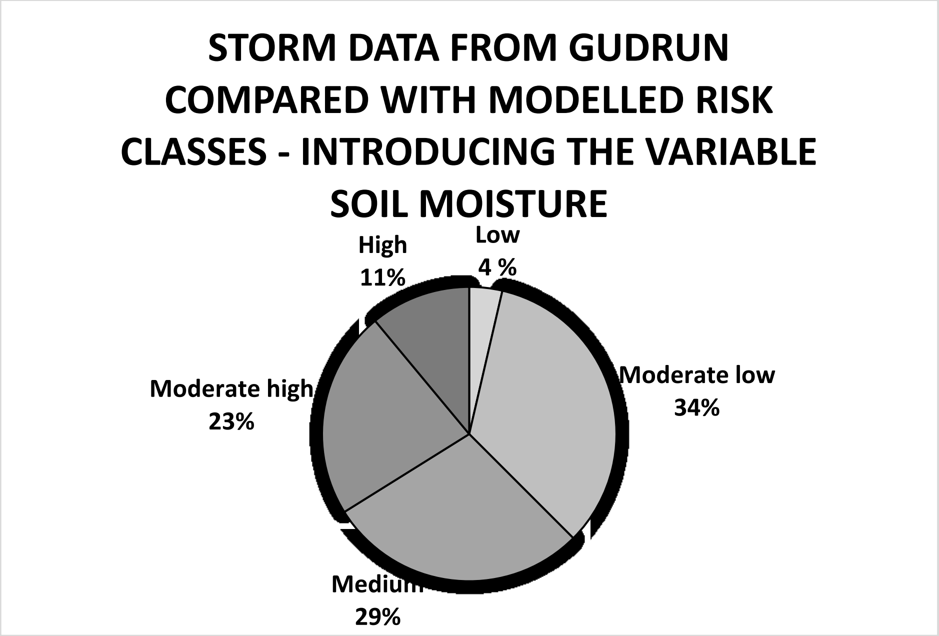

Figure 11. Soil moisture was introduced to Equation 2 and the variable Topographic exposure was excluded. The storm damage data falling into the three highest classes increased slightly. In this Diagram 62 % of the pixels fell into the three highest classes.

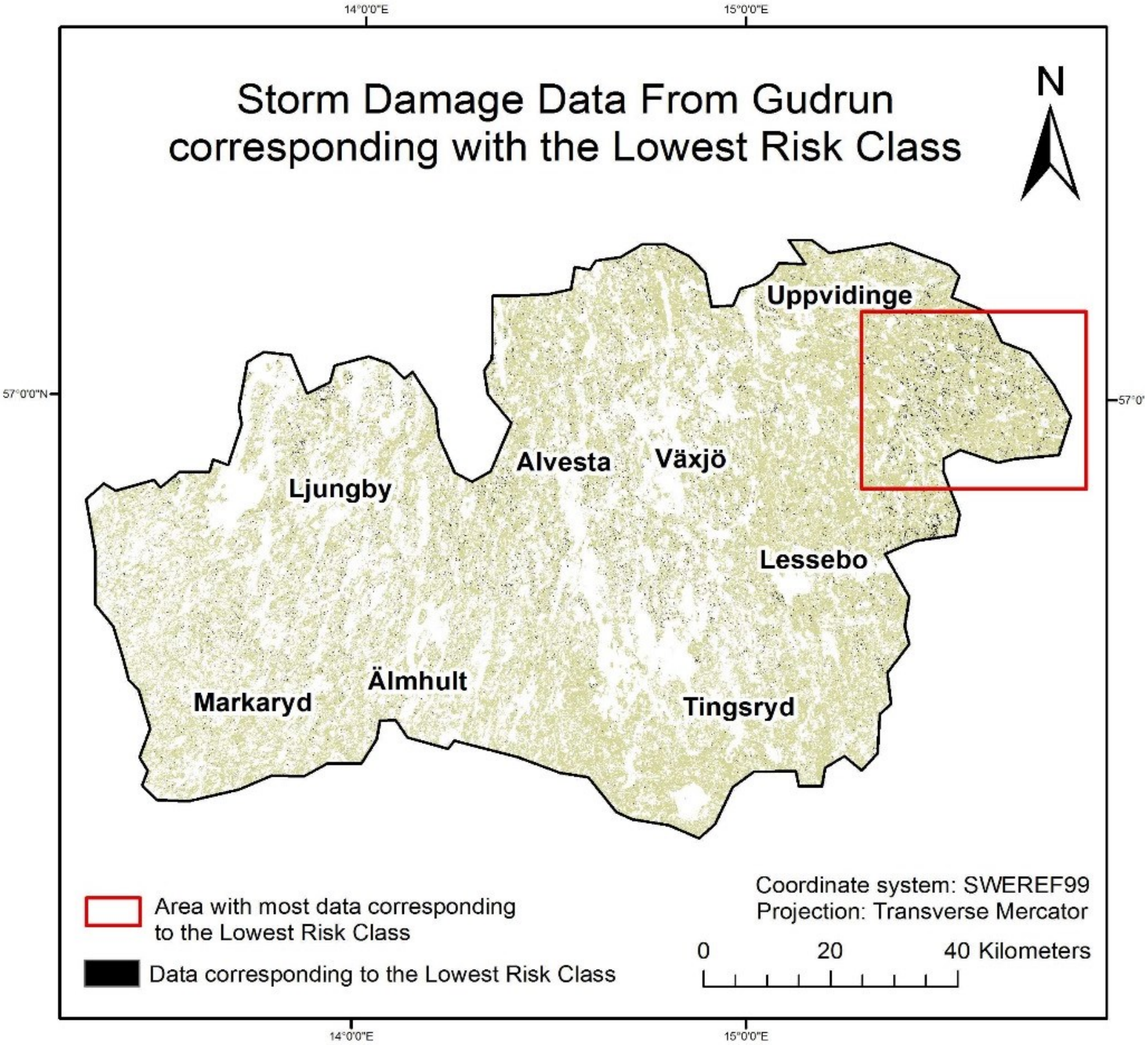

Figure 12. Storm damage data from Gudrun corresponding to the lowest risk class, the area in eastern Kronoberg has a particularly high level of storm damage data falling into the lowest risk class.

5. Discussion

This section brings up the advantages and the disadvantages concerning the storm damage model and discusses how improvements can be made and places the concept into a broader perspective.

5.1 The Classification modelling of Risk for Storm Damage

The classification model is a fairly simple modeling tool to estimate the areas at risk of storm damage. By evaluating the abiotic and biotic factors it becomes possible to perform the classification and weigh the variables together. An evaluation of both abiotic and biotic factors is necessary to understand why storm damage varies within a landscape The model result facilitates an assessment of the landscape and its characteristics, and localizes the areas at particular threat. This is a useful tool for both communities and forest owners. When these areas of high risk have been identified it is easier to make decisions regarding forest management strategies or for instance when planting new trees. This will help society to prevent damage in the future. The variation in the landscape is rather apparent, which proves that patterns for storm damage can be detected by using this tool and allows analysis (Figure 8).

5.2 Interpretation of result

The modelled risk classes show spatial trends in the landscape of Kronoberg where the risk for storm damage is concentrated in the center of Kronoberg, and the risk decreases in the upper eastern area (Figure 6). Generally, the modelled risk classes and the actual storm damage data from Gudrun have similarities. In both cases it gives the highest values in the center and lower values and less damage in the east. Also in the very western areas the values are reasonably low for both the model and the actual storm damage data (Figure 7, Figure 8). The area that raises the most interest is the classified low risk area in the east. This area is generally rather well classified to the “low risk area” with reference to the storm damage data from Gudrun (Figure 5). Although, it appears that this entire area should not be regarded as low risk, as rather high proportion of the actual storm fellings occurred in this area classified as “low risk” (Figure 9). This can possibly be explained by the altitudes of the area. The altitude may both enhance and reduce the risk of storm damage. The trees on higher altitudes are regularly exposed by winds and are therefore acclimatized to this kind of condition. They acclimatize by developing stronger roots which increase the resilience for wind throw, although, trees at slopes facing the wind direction experience a greater risk for damage (Schütz et al. 2006). The trees on higher altitudes are also dependent on slope direction. Additionally, the altitude affects the water content in the ground. Water commonly streams downward and therefore the soil in these areas is drier than in the valleys. Drier soils can benefit the root anchorage by fixing it tighter to the ground (Mayer et al. 2005). Another factor having an effect on the eastern area is the tree species. By studying the result of the multiplicative approach (Figure 7), it becomes evident that the concentration of spruce is somewhat lower in this area and thus reduces the risk for storm damage (Figure 7). As concluded, trees acclimatize to wind, but when a wind flows over a hill there is also a risk for gusts. Gusts are winds that are enhanced in a downslope causing wind turbulence which consequently increases the risk for wind throw and storm damage (Gardiner et al. 2013). Altitude is a challenging variable and for this type of landscape it may be better to only apply soil moisture data and wind exposure. In fact, when the model was run with soil moisture added to the equation and topographic exposure excluded the result was slightly improved.

This is visualized in Figure 11. where a greater proportion of storm damage data from Gudrun corresponded to the modelled higher risk classes.

When the multiplicative approach was adjusted and the weighting was reversed (Giving deciduous trees the highest weight) the result gave a great contrast from the original version of the model (Spruce having the highest weight) (Figure 10). This result confirms that tree species has a particular impact to the extent of storm damage. As described in chapter 2.4 the western part is generally drier and has a quite low range of precipitation which could explain the low values in this area (Figure 6).

5.3 Discussion of Variables

The selection of variables was done with respect to what seemed appropriate for the landscape of Kronoberg and depending on available data. The first decision was to discriminate between tree species, and thereafter giving them a suitable weighting. Spruce received the highest weighting with reference to earlier performed studies. Studies unquestionably agree on the point that spruce is the most susceptible species (Valinger and Fridman 2011; Schütz et al. 2006; Schmidt et al. 2010). The results clearly demonstrate the species significance (Figure 10).

Implementing the altitude in the equation was challenging. Some studies show that higher altitudes have less storm damaged trees (Nilsson et al. 2007; Fridh 2006; Schmidt et al. 2010). But also that slopes facing the wind direction increase the risk for storm damage (Fridh 2006; Schmidt et al. 2010). A Swedish report conducted after the storm Anatol evidenced that gentle slopes between 1-2 degrees gave the highest occurrence of damage (Nilsson et al. 2007). Topographic exposure does not really take the effect of the slopes into account, but it includes the aspect of wind exposure and comprises the eight cardinal angles (N, NE, E, SE, S, SW, W, NW).

When referring to the landscape of Kronoberg, it can also be discussed whether soil depth is an indicative variable or not. The soils in Kronoberg are predominantly deeper than 45cm. This means that there is a quite low data distribution with one outstanding category (>45cm). In a report conducted after Gudrun, the storm damage was only located at areas with a soil depth deeper than 20cm (Fridh 2006). From this finding it can be concluded that storm damage mostly occurs on deeper soils. Nevertheless, almost the entire county has soils deeper than 45cm (Appendix 3), therefore this finding does not really contributes with knowledge regarding the soils impact on storm damage. However, it stresses the importance of scrutinizing each variable closely, and especially overseeing the distribution of it. The small areas containing a depth less than 20cm is located at the highest elevations (Appendix 3, Appendix 5). This could be an argument that the storm damage is more likely related to the elevations and the topography instead of the soil depth in Kronoberg.

Calculating the slenderness ratio is a simple way of describing the tree's stability (Cucchi et al. 2005), which is appropriate for this kind of study. This method also includes both the size of the stem and the tree's height, and both are proved to make an impact on the tree's resilience (Zubizarreta-Gerendiain et al. 2012; Blennow et al. 2010; Fridh 2006). An improvement of the result could have been to weight this variable less. The reason is that Slenderness ratio could be misleading, as a lower ratio of h/d does not necessarily have to be a sign for higher stability but also imply on trees with larger crowns which would increase the wind load (Gardiner et al. 2013).

5.4 Limitations of the model

To begin with the classification model aims to be as simple as possible and the purpose is to merely give an indication of areas at risk. However, there are some uncertainties that can be brought up, for instance the selection of equations and ratios. The equations and ratios are based on statistical/empirical methods and might not be as realistic as for example a mechanistic one. Unlike the mechanistic model, one which is based on the understanding of the behavior of a system's components, the empirical model is based on direct observations (Tham 2000). Also the equations have not been applied to a high number of studies and may evidence that they are not that effective. For a more detailed study other variables such as volume of forest, density of forest, gap size and exposed edges could have been applied.

There are several factors controlling the degree of storm damage and it is therefore challenging to establish the ones with the highest impact. Storm damage to forests can also be due to both indirect and direct impacts, as well as the way the forest is managed. But including all potential factors that could have influenced the storm damage would be rather impracticable. For this reason the focus was put on the climatic factors and the forest management was excluded, and this can be regarded as a limitation.

Regarding data there are some aspects that could have been improved, for instance the digital elevation model. The digital elevation model had a resolution of 50x50 meters. This is a rather coarse resolution and local depressions will not be displayed. Particularly, for Kronoberg this is a concern. The landscape is already quite flat and with the resolution of 50x50 meter the elevation becomes quite hard to assess. Instead the aspect could have been the only variable representing the elevation data. There was an option to choose elevation data with much higher precision (2x2 meters resolution) (Lantmäteriet 2015b) but the data was very unsuitable for the purpose of estimating areas at risk for storm damage. The files were very large and it would have brought great challenges to integrate it with the rest of the model. Another data with some uncertainty was the soil data which was converted from a point layer into a continuous raster by interpolation. When performing an interpolation the unknown values are based on already existing measures. Therefore, it does not necessarily reflect the reality, and also it is very dependent on the number of points. The data which almost certainly brought the most error is the storm damage data from Gudrun. Estimating damage after a storm event is problematic and commonly this type of data is either underestimated or overestimated (Nilsson 2008). To minimize the errors and facilitate a more reliable method of classifying a landscape into risk classes, it would be advantageous to use data from more than one storm event.

5.5 Other factors having an impact on the result of the model

The model's accuracy is dependent on a few factors and one of them is the timing of the storm event. If a storm strikes in the summer the circumstances regarding the trees are quite different from the winter season. The deciduous trees are normally full of leaves, and this increases the wind load and thus makes the deciduous trees more prone to storm damage (Gardiner et al. 2013). If the model would consider the seasonal variability the weighting must be adjusted accordingly, for example, giving deciduous trees a higher impact. The reason why the winter season is assumed is that the majority of storms in Sweden occur during this time of the year (Nilsson 2008). Another factor having an impact on the result of the model is the probability of change in wind direction. The general wind direction for the study area is westerly winds (Wern and Bärring 2009). These westerly winds are accounted for in the modelling by giving them the highest classification score, which means the highest impact to storm damage. However, there is always a chance of winds coming from another direction and this would signify less accuracy for the model.

5.6 Future Perspectives and The role of Forest management

According to studies surveying the susceptibility of forest in a changing climate, models show that particularly Norway spruce will be negatively affected. A plausible consequence with a changed climate is an increased risk of prolonged drought periods. This will have a negative impact on spruce's superficial root system due to changes in the soil. Likewise, in areas with great exposure to tropospheric ozone, as is the case for southern Sweden, the drought effects can be even more pronounced. Another consequence is increased risk for spring frost damage. This would primarily affect the establishment phase of seedlings and planted trees (Schlyter et al. 2006). The tree species Pine is also reasonably susceptible. Forest simulations have been performed on Scots pine to investigate its resilience to a 4 degree temperature increase. From the wind-speed simulations it appeared that winds at the speed of 11–15 m s−1 would be enough to uproot trees with unfrozen soil conditions. With respect to climate changes this can lead to an increase in the loss of timber due to wind thrown trees (Peltola et al. 1999). Although, the climate effects already affect the ecosystems it is concluded that adapting the forest management will possibly minimize the risk of damage in the future.

The current challenge is to integrate the long-term goals and the choice of selecting effective strategies to reduce the risks (Jönsson et al. 2013). As it appears from current storm damage data and predictions regarding the future, adaption is needed (Blennow et al. 2010; Nilsson 2008). Leaving the forest management as it is does not seem to be a reasonable decision. Although, the arguments for planting the vulnerable species Spruce are a few. One argument is that the moose eats the pine plants, and therefore Spruce is more desirable (Ingemarson et al. 2007). Other arguments are that spruce has a high growth capacity, economical advantages and the management around it is fairly easy (Fridh 2006). In Sweden there are also bylaws for the selection of species. These bylaws encourage foresters to choose tree species with respect to the climate and soil conditions with a combination of the adjacent forests. For instance, Spruce prefers fertile soils and are much more suitable than Pine for this type of soil (Albrektson et al. 2012). The soils of Kronoberg predominantly consist of till (Lantmäteriet 2015a), and it is proven that those types of soils positively influence the tree growth for Spruce (Johansson 1995). However, when taking the storms and storm damage into account options must be considered.

Suggestions to reduce the risks are for instance, adapting rotation length, target diameter or introducing deciduous trees to spruce stands (Albert and Schmidt 2010; Schütz et al. 2006). Introducing deciduous trees to a spruce stand appears like a feasible option, as a number of studies have indicated that both stability and productivity increases (Pretzsch and Schütze 2005),
which is in line with the results of this study that indicated that the risk of storm damage would be reduced if the landscape consisted of a larger proportion of broadleaved trees (i.e. Model run 2, figure 10). Generally, spruce is the most productive species, but considering disturbance factors like storms, insect infestations etc., a mixed stand would have a higher resistance and therefore be more economical in a future perspective (Schütz et al. 2006; Pretzsch and Schütze 2005). Additionally, birch can have a positive influence on spruce,

during spring it can work as frost protection (Albrektson et al. 2012). Also when managing the forest it is important to remember that removing tree edges might bring risks. If a tree edge is removed the forest previously unexposed becomes very susceptible due to less social root support (Gardiner et al. 2013) Also the edges direction in relation to the wind affect the risk for damage (Skogsstyrelsen 2006) Models have high significance and are necessary tools to support the forest management with information. Results from a study proves that site productivity models can generate useful information to support forest management decisions (Albert and Schmidt 2010).

6. Conclusion

Developing a model with help of GIS is an effective way of assessing the risk for storm damage.

A classification model is a useful tool to evaluate the landscape's risk for storm damage and to get indications on where areas have a high alternatively a low risk. This model could possibly be useful if a higher resolution was utilized. The model gives indications that tree species may have a large impact on the storm damage, but are interacting with other factors such as topography, tree stability, soil moisture and exposure. For landscapes with flat topography soil moisture is a preferable measurement of the altitude's impact. Regarding forest management we must improve the adaption strategies to overcome storm damage to forests. A suggestion is to encourage establishment of mixed forest stands at a rejuvenation stage.

"All models are wrong, but some are useful"
George E. P. Box

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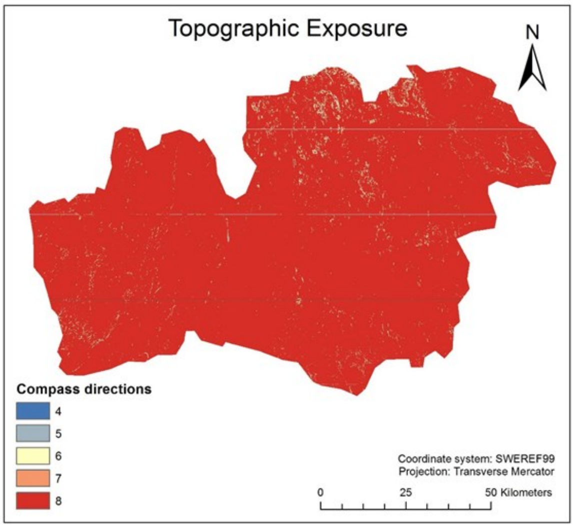
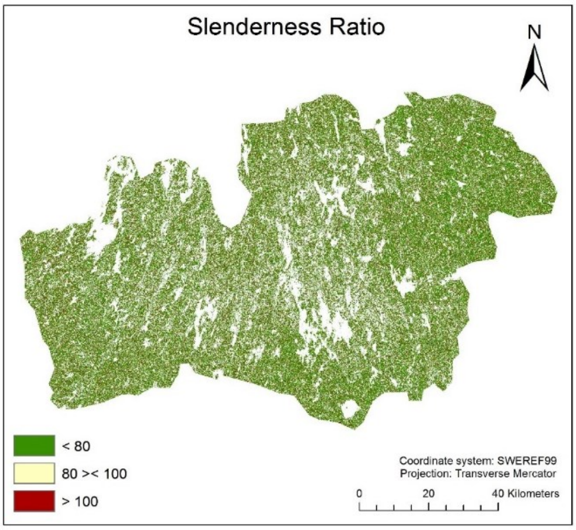
8. Appendices

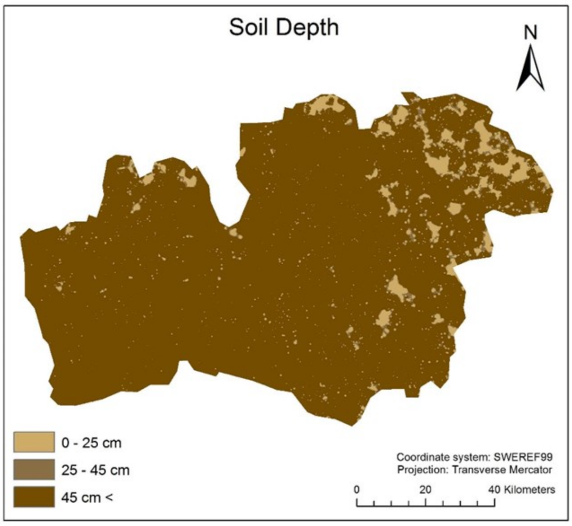
Appendix 1 to 5 displays layers used for the procedures performed in ArcMap. Appendix 6 to 7 gives a visualization over the geostrophic wind distribution which were layers used to establish the weighting for aspect.



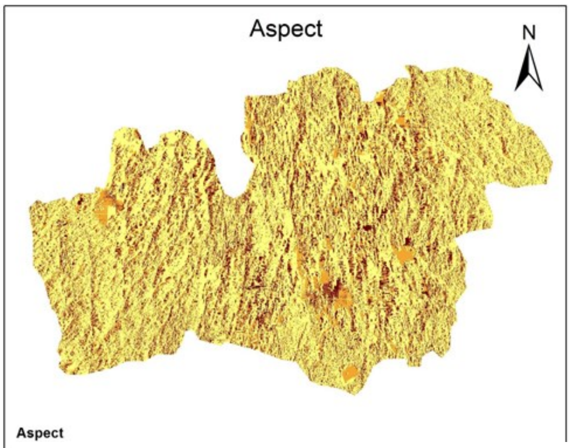
Appendix 1. The result of calculating Topographic Exposure.



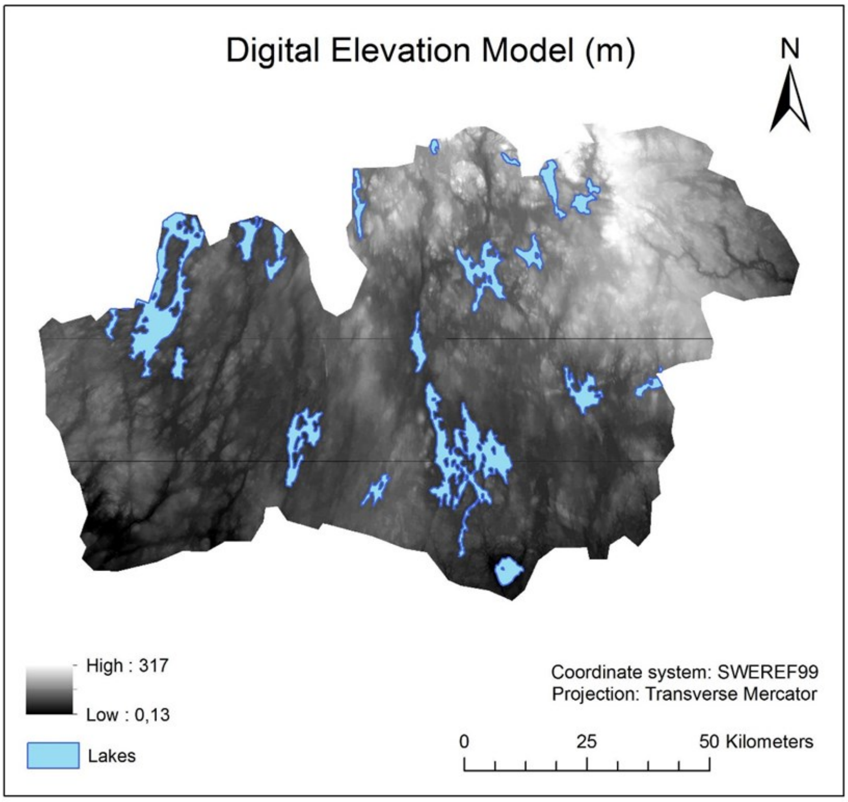
Appendix 2. The result of calculating Slenderness ratio.



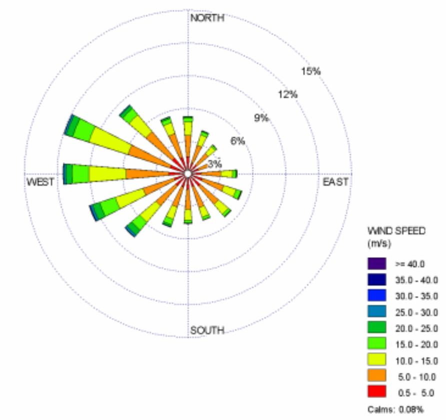
Appendix 3. The distribution of soil depth.



Appendix 4. The result of calculating aspect on the elevation model. West indicates that the landscape is exposed to this direction.

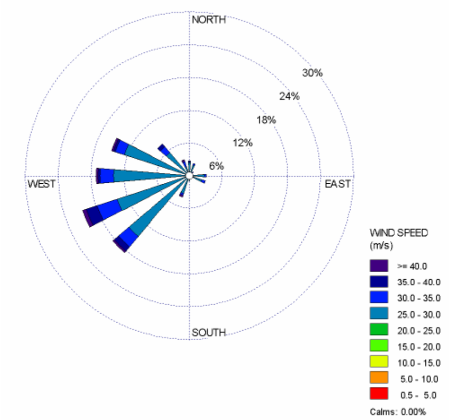


Appendix 5. Elevation model over Kronoberg County. The altitudes are highest in the east and lowest in the west.



Figur 47. 1991 – 2008, G-V-L

Appendix 6. Frequency of geostrophic winds distributed in different wind directions for 18 years. The measurements were done in Göteborg – Visby – Lund.



Figur 55. 1991 – 2008, G-V-L, >25 m/s.

Appendix 7. Frequency of geostrophic winds distributed in different wind directions during 18 years, only showing winds reaching to a speed higher than 25 m/s. The measurements were done in Göteborg – Visby – Lund.

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

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