Impacts of winter storm Gudrun of 7th – 9th January 2005 and measures taken in Baltic Sea Region

Simo Haanpää[1], Samuli Lehtonen[1], Lasse Peltonen[1], Elena Talockaite[2]

Photo:Kaisa Schmidt-Thomé

[1] **Centre for Urban and Regional Research (YTK)**
PL 9300, 02015 TKK, Finland

Telephone +358-9-451 4426
Telefax +358-9-451 2140
Email simo.haanpaa@tkk.fi
URL www.tkk.fi/Units/Separate/YTK/index.html

[2] **Environmental Centre for Administration and Technology (ECAT)**
Lydos 4, Lt-44213 Kaunas, Lithuania

Telephone +370 37 423053
Telefax +370 37 422797
Email elena@ecat.lt

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1. Introduction

This report is produced in the frame of project „Developing Policies and Adaptation Strategies to Climate Change in the Baltic Sea Region“ (ASTRA) which is part-financed by the European Union within the BSR Interreg IIIB Neighborhood Program. The project duration is from June 2005 till December 2007.

The main objective of the ASTRA project is to assess regional impacts of the ongoing global change in climate and to develop strategies and policies for climate change adaptation. More information about the project is available on the project web-site (www.astra-project.org).

One of the aims of ASTRA is to address the need for adaptation to climate-borne threats already felt today, such as winter storms and flooding. Threats arising from climate change are also seen manifold in the Baltic Sea Region, as extreme weather events such as extreme temperatures, droughts, forest fires, storm surges, winter storms and floods are seen to become more common. In the scope of ASTRA, extreme weather events will function as focusing events for the future. Comprehensive assessment of the impacts of such events, as well as measures taken during these events, will give a possibility for different stakeholders to understand the implications of extreme weather events to different sectors and regions around the Baltic. Winter storm Gudrun that took place on January 7-9, 2005 is a prime example. As it affected almost all countries participating in ASTRA project, the storm was selected as a case study.

The general overview of impacts and measures taken in the Baltic Sea Region during the winter storm is a cross-sectoral comparative study on the impacts of Gudrun. The overview is prepared in co-operation by the Environmental Centre for Administration and Technology (ECAT) and the Centre for Urban and Regional Studies (CURS) at Helsinki University of Technology, using information and data provided by ASTRA project partners in participating countries. Based on the data obtained from partners, additional research on the most important themes has been made. TuTech Innovation GmbH will transfer this data into a web application.

2. Methodology

The main goal of the general overview is to gather information about the impacts of and responses to Gudrun at national and local/regional levels. In order to reach this goal two questionnaires were developed and sent to project partners. The first questionnaire aimed at gathering country level information, while the second questionnaire gave a possibility to get the local or regional insight.

Both questionnaires consisted of 3 sets of questions. In the first set, project partners provided basic data on the winter storm Gudrun in January 2005 (e.g., highest sea level measured, maximum wind speed, regions and locations most affected, etc.). In the second set, information about winter storm impacts (human, economic and natural losses) was collected. The third set of questions was dedicated to the assessment of response and adaptation measures taken before and after the storm, such as main problems occurred and the improvements made after the storm.

Country level information was gathered from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden. Case study level information was gathered mainly from Espoo and Itä-Uusimaa region (Finland), Stockholm county (Sweden), Gdansk (Poland), Tallinn and Pärnu (Estonia), Klaipeda city and Curonian Spit (Lithuania) (see figure 1).

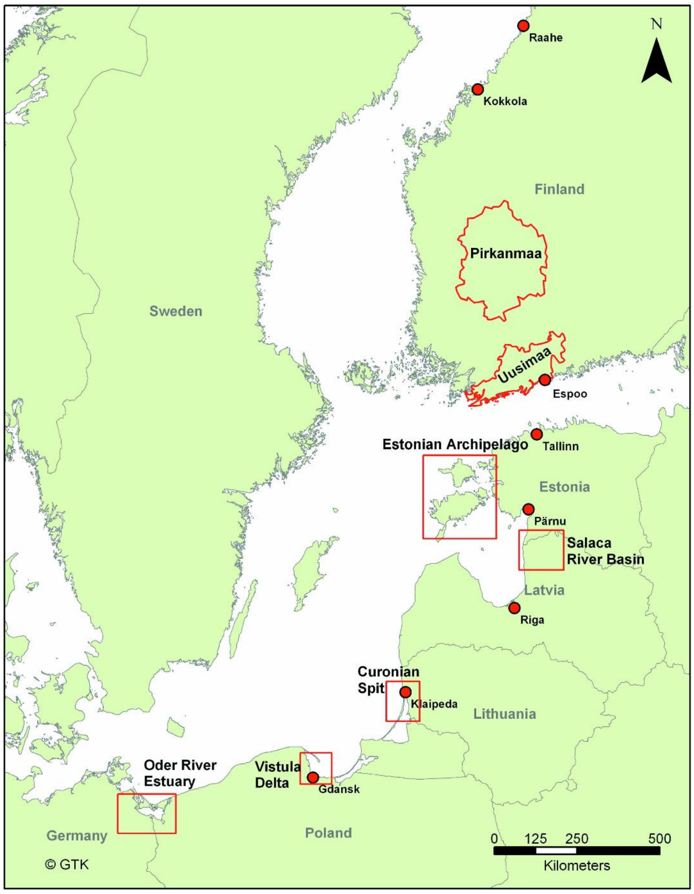

Figure 1. A map of the Baltic Sea Region indicating analyzed countries and case study areas

3. Impacts of Gudrun on the Baltic Sea Region

3.1 Meteorological overview

The winter storm Gudrun (a name given by the Norwegian Meteorological Institute, also known as Erwin) of 7th-9th January 2005 was selected as a case study in ASTRA-project because it was a recent event that affected almost all of the participating countries around the Baltic sea. In this area, the storm was considered the fiercest since 1969 based on its spatial reach and on the losses it caused. Seven people were left dead in Sweden and four in Denmark, with total number of casualties reaching 17 (including Ireland and UK) (GuyCarpenter 2005).

The winter storms hitting northern Europe form on the so-called polar front. This is a wide belt between 50 and 60 degrees latitude, where cold polar air and southern air masses warmed by the oceans meet. This is the reason behind the quite variable weather normally experienced in the countries bordering the Baltic Sea. During the polar winter, as the high latitudes receive hardly any solar radiation and the southern air masses are still heated by both the solar energy and the warmth stored by the oceans, the difference in temperatures between these two air masses becomes large enough to trigger the storms. As cold polar air pushes southward, it sets the air masses in an anti-clockwise spin surrounding a deepening centre of low pressure. If the difference in temperatures persists, the storm front may grow to a diameter of 3000 km's and possess wind speeds up to 200 km/h (55 m/s) (Munich Re 2000).

In this case, the low pressure path traversed over the Scottish highlands, Southern Norway and Sweden, reaching Finnish coast a couple of hundred kilometres south of Kokkola. It then continued towards Russian Karelia, already considerably weakened (Suursaar et. al. 2006). The belt of maximum wind speed and damage it caused is left just south of the storm centre (see figure 2, according to GuyCarpenter 2005). This is because the wind trajectories and the trajectory of the storm itself are unidirectional on the right hand side of the storm (as the winds always circle the point of low pressure anti-clockwise following the pressure gradient) and thus enforce each other (Suursaar et. al. 2006).

An interesting meteorological feature of the storm was a powerful jet stream situated right over the low-pressure centre of the storm that greatly intensified its damage potential. The jet stream dragged air upwards from the low pressure point intensifying it further and causing moisture to condense to form clouds and precipitation. On the other side the dried air rushed downwards as a so called sting jet, a strong upper-level wind descending to the ground (GuyCarpenter 2005). The comparison of the maximum wind speed (gusts) shows that the highest wind speed was measured in Denmark (up to 41-46 m/s on the coast) and Estonia (37.5 m/s) (see Table 1). In all other analyzed countries the maximum wind speed was above 30 m/s, which corresponds to the highest force of the Beaufort Wind Scale1 (Force 11-12).

[1] The *Beaufort Scale* or *Beaufort Wind Force Scale* is a system for estimating wind strengths without the use of instruments, based on the effects wind has on the physical environment. The behaviour of smoke, waves, trees, etc., is rated on a 13-point (forces) scale of 0 (calm) to 12 (hurricane).

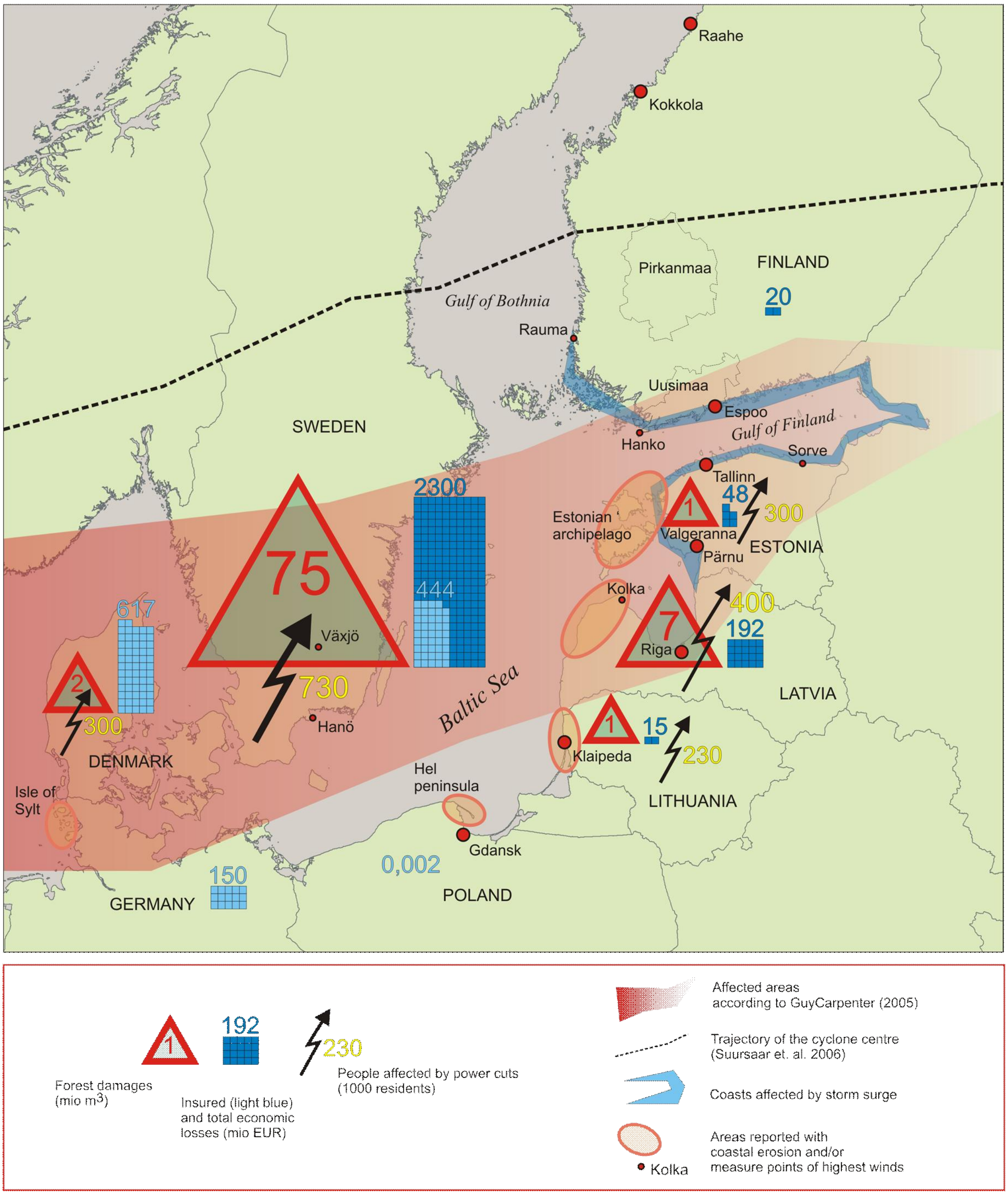

Figure 2. A map of the Baltic Sea Region indicating the effects of Gudrun in the analyzed countries and case study areas

The highest sustained wind speed was measured in Sweden (42 m/s in Hanö and 33 m/s in Ljungby and Växjö – worst hit areas) (table 1). In other countries the maximum sustained wind speed was above 24 m/s, which corresponds to the Force 10-12 of the Beaufort Wind Scale. According to a report by the insurance company GuyCarpenter (2005), the sting jet might partly be the reason behind the vast forest losses in Sweden and Denmark.

Table 1: Maximum wind speed measured in different countries during Gudrun (Erwin)

Country	Maximum wind speed (gusts, m/s)	Maximum wind speed (sustained, m/s)
Denmark	41-46 m/s on the coast, 30-33 m/s over the whole country	28-34 m/s (mean values)
Sweden	42 (Hanö), 33 (Ljungby & Växjö, worst hit areas)	33 (Hanö)
Poland	34	20
Lithuania	32	26
Estonia	37.5 (Kihnu, Sorve)	28 (Sorve)
Finland	30, Hanko Tulliniemi (Southern coast)	24, Lemland Nyhamn, Rauma Kylmäpihlaja (Southern coast)

3.2 Cost and characteristics of Gudrun

According to Meiner (2006), both the trends in number of weather-related events and in insured losses they cause have been rising during the past decades. In fact, the cost of weather-related events has doubled each decade starting from the 1970's. The average annual cost during the past 15 years has averaged 12.8 billion EUR (16 billion USD).

The winter storm of January 2005 was exceptional, in the scale of the Baltic Sea region. Converium Holding Ltd. of Switzerland (2005) estimated the losses for industry alone to reach 1.1 – 1.5 billion EUR (1.3 -1.8 billion dollars). Referring to the information collected for ASTRA and numbers published by the insurance company Guy Carpenter (2006), total damage caused by the storm would be roughly 1 billion EUR in Nordic and Baltic countries alone. Swiss Re calculated the insured losses alone to reach 1.5 billion EUR (1.9 billion USD) (Swiss Re 2006). It has to be noted, that the share of non-life insurance policies is far bigger in the Western Europe than it is in the Central and Eastern Europe. Although there is a substantial growth in the east, the number of insurance policies is still considerably lower in the east, even when compared to the GDP (Swiss Re 2006).

The most affected sectors found in ASTRA and presented here present almost all of those listed by EEA as being most vulnerable towards climate change in Europe. Coastal zones receive a lot of attention, as coastal erosion and flooding are seen both as most threatening and most expensive effects of climate change. Often the vulnerable coastal zones are already under an anthropogenic pressure. It is seen, that the cost of floods could be way over 10-fold in 2080's, compared to the annual cost of 6.5 – 8 billion EUR paid today (Meiner 2006). Percentage of built up area near the coast is luckily is smaller on the Baltic Sea region than on other European coasts (Meiner 2006).

The winter storm of Jan 2005 did not reach the impacts of the fiercest winter storms of past years, namely Lothar and Martin of 1999 and Jeanett of 2002. The two storms of December 1999 still are the most expensive storms recorded, together totalling over 12 billion EUR in insured damages. 125 people were killed and nearly four million affected. Forest losses were massive in Southern Europe (EEA 2003). According to EEA (2003), based on studies made by the insurance company Swiss Re, storms like these have a return period of only ten years however. Damages worth over 1 billion EUR occur every two or three years, as in case of Jeanett in 2002. In area affected they were exceptional however (EEA 2003).

Figure 3: Storm damages on Estonian coast (Photo: Sten Suuroja)

Setting the cost and casualties experienced aside, the effects of the storm were interesting in their spatial variability. In Finland for example, the storm raised the sea-level to new record heights in many places along the coast, although the wind speeds did not even reach that of a severe storm (Ilmatieteen laitos 2005). The direction of the storm and its spatial reach caused a storm surge that was felt as substantial sea level rise on the coasts transverse to its path, like that of Finland and Estonian archipelago and namely Pärnu. This phenomena forced many actors to contribute to mitigating the damage and in Finland ignited discussions on the adaptation capacity towards similar extreme events. The situation was quite similar in all of the Baltic countries, with excess flooding common. It must be noted, that the scale of impacts caused by Gudrun differs from country to country.

Remarkable feature of the storm were the vast power cuts, that for example in Latvia cut some 60 per cent of the country's population from power. In Denmark and in particular in Sweden the storm caused huge forest losses, with damages totalling some 230 million EUR in Sweden alone. Germany and Poland luckily escaped without major damages, although excessive coastal erosion was reported in places in both countries. In all, the direct damages from high wind speed were portrayed just south of the storm centre, whereas in the southern coasts damage was caused mainly due to indirect impulse like wave action. The effect of the wind was still felt in the Baltics as a result of the water masses driven by the storm causing storm surges on the coasts.

3.3 Human losses and affected people

According to the data provided by ASTRA project partners, inhabitants of Sweden, Denmark and Estonia were most affected by the Gudrun. The number of casualties includes 9 in Sweden, 4 in Denmark and 2 in Germany. 14 people were injured in Estonia and needed hospital treatment – 13 of them suffered from hypothermia. Four persons were injured in Lithuania, and two in Germany.

However, the number of people affected in each country was much higher. Sweden counted millions of affected people, Denmark reported between 150 000 and 200 000. 135 households were evacuated. In Estonia, approximately 18 % of inhabitants (254 000) were affected by the storm. Numerous houses (mainly in Pärnu and Haapsalu) were affected by coastal floods caused by the storm surge and about 600 inhabitants were evacuated due to the severe weather conditions. In Germany, people suffered the time loss and stress because of the problems in the transport system.

The storm took its toll even after it had passed; According to the Swedish Meteorological and Hydrological Institute, 20 people were left dead after the storm while conducting dangerous tasks related to the damages it caused. The total of affected people in the BSR region can be estimated in hundreds of thousands.

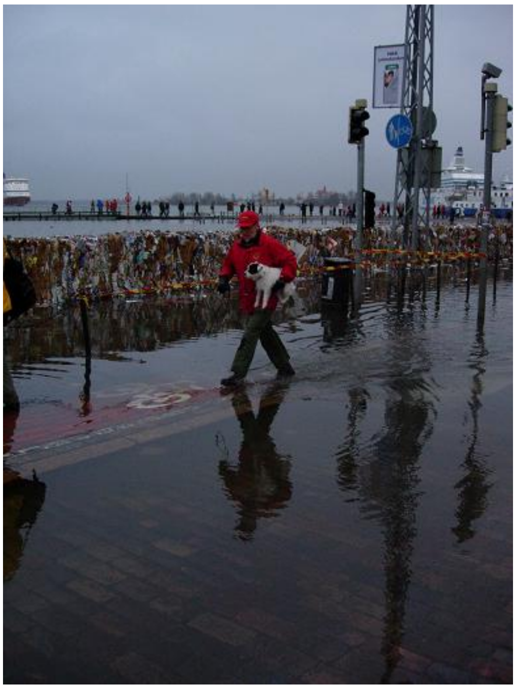

Figure 4: People gathered to observe the rising sea-level
(Photo: Kaisa Schmidt-Thomé)

3.4 Impacts on natural systems and human well-being

The question on how people were affected can be opened through looking at the impacts of the storm on natural systems. The main effects of the storm on natural systems can be divided in three categories;

1) Forest losses and partly related power cuts, especially in Sweden and Denmark but also in the Baltic countries; as direct wind-related damages

2) Accelerated coastal processes, namely coastal erosion, in Latvia, Lithuania and Estonia, but also in Poland and Germany; through risen water-level and heavy wave action during an ice-free period

3) Coastal flooding in Estonia, Finland and Lithuania, extending to Russia; as a result of a storm surge pushed by the storm front

3.4.1 Forest losses

Forest losses were one of the most significant environmental impacts of Gudrun. Record damages over the past 30 years were observed in Sweden. However, in other countries, such as Latvia, Denmark, Estonia and Lithuania, forest damages were significant as well. Forest losses in Poland were significantly lower that those in the countries mentioned above (see Figure 6).

Figure 5. Forest damages were extensive in Sweden (Photo: from SMHI, 2005)

Spruce forest found susceptible to storm damages in Sweden

In **Sweden** the storm fell about 75 million m^3 of trees, totalling the normal *annual* harvest in the whole country. It was seen, that the path of the storm over the Norwegian highlands may have enhanced the wind-speeds over Sweden and Denmark, as part of the air masses circled the obstacle (SMHI 2005).

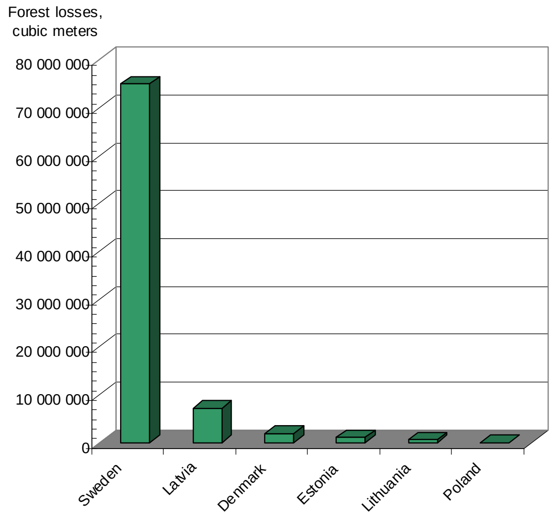

Figure 6. Forest losses in the Baltic Sea Region after Gudrun

Considering the forest damages, wind speed gusts are the prime concern. In Finland it is seen, that the mean wind speed of 15 m/s and gusts of 30 m/s seem to be the critical threshold for forest damages (Kellomäki et. al. 2005). During Gudrun, the gusts were even over 40m/s on the west coast of Sweden, and only a little lower inland. What is notable however and many times more interesting in terms of adaptation, was that the structure of the affected forests had a big impact on the amount of damages. As pointed out by SMHI (2005), the widely planted spruce forests are vulnerable towards storm winds. In Sweden the forests felled were mainly 30-40 years old, thus taken root after the previous big storm events in the area in the end of the 1960's. As can be seen from the figure 3, the share of coniferous trees of all trees cut in Sweden is very high. Compared to pines for example, spruces have a shallow root structure that weakly anchors the trees to the soil. This effect can clearly be seen in the pictures shown in the report provided by SMHI (2005).

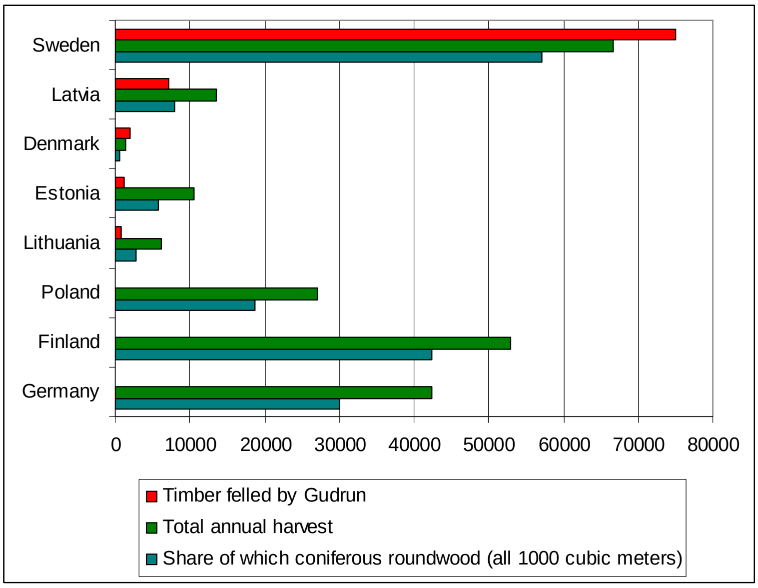

Figure 7. Comparison of the storm losses, annual harvest and the share of coniferous timber in the countries of BSR (Data according to Metla 2004).

It has to be seen, that many factors affect on the sturdiness of forests. Central are the means and forms of thinning and cutting regimes, as a freshly or extensively thinned plot is more vulnerable towards wind damages (Kellomäki et. al. 2005). During the past century the area of planted forest has arisen considerably. Old fields and meadows have been forested and ditches dug in the forest floors themselves. This has increased the area of forests in Sweden, but also brought to forestry soils that are less steady for the trees to grow in. Because of the heavy machinery used for harvesting, the amount of dozy timber vulnerable to storm winds is on the rise (SMHI 2005). It can thus be said that the actions of humans have greatly decreased the natural adaptive capacity of the forests towards extreme weather events.

Natural processes remain the greatest reason for forest damages however. According to Kellomäki et. al. (2005), at the moment the mean return period of major wind damages in Finland is 2-3 years. As climate change progresses, the rate of harmful storm events is seen to be on the rise. It is also worth mentioning, that the growth rate of spruces is to drop dramatically in Southern Finland during the next hundred years due to increasing drought periods (Kellomäki et. al. 2005). In global scale the lack of precipitation is forecasted to be more severe towards southern Europe. Thus the dominance of spruce forests and feasibility to cultivate it extensively might be threatened. Many factors define the composition of tree species in young forests however, apart from human interventions the distribution of large herbivores like moose's being one of the key factors (Kellomäki et. al. 2005).

Sturdier tree species introduced in Denmark to lessen forest damages

In **Denmark** the damage was greater still, as the amount of felled forest of 1,5 – 2 mio m^3 equals to 1.5-2 times the annual conifer harvest. The cost was some 300 mio DKK (almost 40 mio EUR) (MIM 2006). Again, mainly conifers, presenting the main forest type in Denmark were hit. Interestingly, after the damage caused by storm Anatol in 1999, the forest owners have received support for clearing and replanting the forest with sturdy tree species. First steps towards adaptation have thus already been taken (MIM 2006).

Not necessarily a problem in Denmark, increasingly the forest soils are dried by trenches. Acidic soils with low pH-value however, like those found on marshlands often target areas for drying, are linked with more storm damages than alkaline soils (UN 2004). It can thus be said that trees are at times planted on soils not totally suitable for them.

Timber prices fall in Latvia as storm-felled timber reaches markets

Latvia suffered forest losses of over 7 mio m^3, more than the normal annual harvest. In Latvia, the annual growth greatly exceeds harvest though, and forested area is on the rise as agriculturally vacant lands are taken to forestry (LTEA 2006). The damages concentrated on the western part of the country, especially to the area between the Baltic Sea and the Gulf of Riga. The amount of timber so suddenly on the market had an effect on the price-level of raw timber, although the storm felled trees are of poor quality in terms of the sawmills' needs. Most forest owners settled to wait for the prices to rise again and normal harvest was delayed (Tuzhikov 2005).

Lessons of Gudrun on wind-induced forest damages:
Modern means of forestry leaves Northern European forests vulnerable against storm damages

Number of storm damages to European forests has been on the rise (UN 2004). The example of Gudrun shows some of the many factors contributing to this; first, the area of forest altogether is on the rise again because of agricultural land lost to forestry. Planted monocultures are more common, with especially spruce forests being vulnerable to storms – partly because of their root structure, partly due to being evergreen plants with large foliage to take the power of winter storms. Rougher harvesting techniques increase root damages and the effect of wind on the forest plots. Trees are also planted on soils not totally suitable for them. The key reasons for forest damages in the future too are natural conditions, especially the relapse period of extreme storm events.

3.4.2 Coastal erosion

Shoreline was affected throughout the southern coasts of the study area. The destruction was most severe in Latvia, which was left on the path of the most destructive winds. Increased water level and wave action together affected the coastlines of Germany, Poland and Lithuania, too. According to EEA (Meiner 2006), reduced sediment discharge of many European rivers because of abstraction of waters increases the coasts' vulnerability to the impacts of climate change.

Figure 8: Eroded foredunes at Lemmeoja, Estonia (Photo: Sten Suuroja)

Coastal processes enhanced by storms a threat to tourism

The westernmost point of coastal erosion on the study area was that of the west coast of Isle of Sylt. Sylt is the northernmost barrier island on the North Sea coast of **Germany**. It is a sandy stretch of 99 km^2, with an eroding western coastline of some 40 km's. Although lying outside the main study area, Sylt was presented here as it was reported being one of the few locations hit by the storm in Germany. It also nicely shows the effects on coastal erosion on tourism sector.

Although the main form of sand transportation is normal wave action, storm surges coming from the west constantly alter the coastline. According to Eurosion study (n.a.), some 1.0 mio m^3 of sediment is lost annually because of the storms. Most of the erosion takes place in the middle parts of the west coast, and the wave action transports the eroded material towards the north and south tips of the island. The east coast holds a salty marsh with tidal deltas. However, no point of extensive accumulation has been noted (Eurosion n.a.)

During the storm of January 2005, some 20 metres of coastline eroded, adding to the only marginal effects the storm had on Germany in general. What makes Isle of Sylt so interesting for the winter storm study though, despite the small damages reported, is that it is an interesting case in the relation between human and nature. The island hosts some 21 000 inhabitants mainly living out of tourism. Especially the middle parts of the island are heavily populated, enhancing the pressure on coastal protection against erosion (Eurosion n.a.).

Project part financed by the European Union

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The protective means, despite apparently being variably successful, have effectively halted the normal development of the island, anchoring it to its current location and resulting in the increasingly arc-like form. The battle against erosion is ongoing, as it is in many areas similar to the Isle of Sylt where human settlements have evolved in stretches of land naturally in constant motion. On Sylt, the rising sea level and stormier winters have increased the rate of erosion during the past 35 years (Eurosion n.a.). The effects faced during Gudrun could thus be taken as yet another reminder of the effects of extreme weather events thought to increase further in strength and on times of occurrence in the decades to come.

Early discussions towards adaptation to climate change have raised questions on the necessity of the current 'hold-the-line' policy of coastal management (Eurosion n.a.). The hard means of protection have in places been replaced with softer beach nourishment means on Sylt. These have proven effective, also economically. However, the cost for nourishing 30 mio m^3 (30 times the annual erosion) was counted in the Eurosion project (n.a.) being almost 115 million EUR. This has to be redone every few years, in order to maintain the current coastline (Eurosion n.a.). Should the recreational values of the island be maintained in the future, this cost could be on the rise. Whatever rise in sea-levels exceeded by post-glacial land subsidence would naturally force the shoreline to seek a new state of balance, and this would likely be somewhat different from the hopes of the inhabitants.

Human impact enhances erosion and vulnerability of the near-shore communities

In **Poland**, the storm hit Hel peninsula, a 39 km long but at places only 300 m wide stretch of sand, extending from the mainland in east-west-direction. It is the key beach attraction in Poland, with over 20 000 inhabitants, many of which work in the tourism sector. Whole of the north shore is vulnerable to erosion, but this especially applies to the very narrow base of the peninsula. The coast is protected by natural dunes some 2-10 metres high, today enhanced by man-made dunes as a part of beach nourishment efforts (Furmanczyk n.a.).

The problems related to Hel peninsula are similar to the problems faced in Lithuania and Germany. The January 2005 winter storm washed away nearly 4000 m^3 of sand from a stretch of 15 km's –nearly half of the length of the peninsula. In addition to this, the waves were reported to have deposited small stones on the beach on a length of 1.1 km's - apparently temporarily reducing their recreational value.

What makes the setting interesting is the effect of man on the natural systems that, as on Sylt, seems to have made the peninsula more erosive and thus more vulnerable towards the kinds of winter storms as the one studied here. In addition to this, the permanent settlements and large population densities make the populations themselves vulnerable towards the natural hazards.

Number of extreme storm events on the rise

As in Lithuania, the erosion/accumulation processes at Hel peninsula are formed by erosive cliffs and the sandy peninsula, along which wave action carries the eroded sediments. In an effort to protect the valuable beaches this system was effectively halted however, by constructing a series of groins starting from the 1940's. Also, a harbour was constructed at the base of the peninsula in 1936, further halting the sediments and increasing the erosion (Furmanczyk n.a.). In this sense the situation resembles that of Isle of Sylt as well.

Most of the groins were destroyed in 1996 and more subtle methods of beach nourishment were adopted. These include an artificial dune of 4,5 meters that protects the beaches and what is left from the natural dune (Furmanczyk n.a.). The peninsula is more protected from the prevailing westerly winds though, northerly winds being the hardest in terms of erosion. In southerly wind situation accumulation happens, and in general the flux of sediments seems to be more of a two-way system than on the western shore of Germany. The nourishing means have been found efficient, but they are costly and have to be renewed every second year, much more often than on the Isle of Sylt (Furmanczyk n.a.).

The total loss of sediments on the **Lithuania**n coast of 0,57 mio m^3 can be compared to the average annual loss through erosion of 0,1-0,5 mio m^3, depending on the study. No matter the number, the lost because of this one single event is considerable. Another point of comparison would be the havoc of a tanker at Klaipeda in 1981, after which 0,5 mio m3 of polluted soil was removed from the beaches. This together with the development affecting the coastline at Klaipeda harbour is said in the Eurosion report (2002) to have increased the vulnerability of the coast against storms.

However, according to the same document, erosion caused by wave action and storm surges is an integral part of the physical characteristics of Lithuanian coastline. The coastline mainly consists of sand deposits, together with intervening bluffs sensitive to erosion. The outline of the coast would be one of erosive cliffs and accumulation zones following each other, the latter forming sand dune coasts. In many places an artificial foredune of 8 to 15 metres in height behind the beach protects the low-lying coastal areas. The beaches themselves are some 30 to 90 metres wide and at places relatively steep. Their stability differs to some extent from place to place. In places forest plantations are used to stabilize the deposits and to enhance the recreational value (Eurosion 2002).

There is nothing unusual about a storm event battering the Lithuanian coast. In Eurosion report (2002) it is counted, that the area experiences some 73 storm days annually, with wind speeds higher than 15m/s. These events wash the beach and erode the dunes and cliffs behind it. The numbers obtained under ASTRA give a hint on the massive proportions of Gudrun however; in the winter storm of January 2005 some 0,52 mio m^3 of sediments were lost from the beaches, whereas the cliffs and dunes only lost some 0,05 mio m^3 of material.

What is alarming is that the number of similar storm events seems to be rising. According to Eurosion (2002), Lithuania has met with ten major storms in the past fifty years, each considered a once in a hundred years event. The effects of the storms are enhanced, should they follow each other shortly, as it seems to have happened in 1983 and 1986 and in 1990 and 1992. This should largely be due to the short recovery time for the plants protecting the dunes. The nature of the Baltic Sea storms favouring the development of dual storm events and the fact that there is normally no ice to protect the coastline (Eurosion 2002) surely counts towards increasing the coasts vulnerability.

The effect of this on human settlements is low however, since very few settlements are located by the shore. Only in central Palanga and in Sventoli settlement would some 14 000 inhabitants be facing a risk from flooding, should the foredune be broken by a violent storm (Eurosion 2002). This likely explains the low cost caused by the January 2005 storm, counted for the area in the ASTRA -project.

River-sea interaction important in sustaining coastal mass-balance

During the storm a significant part of coastline of **Latvia** was affected. The total length of the affected shoreline is 200 km (40 % of the total length of the marine border of Latvia). The erosion processes influenced coastal forests, urban and natural heritage areas. The area of 100 ha was directly influenced. The volume of washed out material (mainly sand and gravel) was 3.1 million m^3. Also the contour of the coastline was significantly affected and the removed borderline reached 3-6 up to 8-10 meters, but maximally it was 15-21 and even 28 meters (near Kolka).

The areas most vulnerable to erosion in Latvia are located in the south end of the gulf of Riga, where northerly and north-western storms are the principal erosion agents. Although the wave fetch is relatively short, the form of the coast in Jurmala and Riga makes them highly susceptible to storm surges (Povilanskas n.a.). What is interesting is the interaction between the gulf and rivers Daugava and Lielupe. In Eurosion study (Povilanskas n.a.) it was found out that water discharge during autumn and winter has increased, rising the mean sea level on the gulf during past few decades.

The rivers are also an important source of sediments. It is seen, that 90 per cent of sediment discharge should come from river basins (Meiner 2006). Developments of river dams and abstraction of water is to blame, also in Europe, where almost all main rivers are dammed (Meiner 2006). In the Gulf of Riga also dredging of sand from the rivers for construction purposes has increased coastal erosion. Funny enough, sand dredged from the river has also been used to fix and avert the effects of erosion (Povilanskas n.a.).

Following the storm of 1969 some foredunes were fixed with a concrete base. Hard means of erosion protection have proved weak however. Better results have been obtained by foredune and forestry maintenance, although lack of funding seems to be hampering protective efforts. Building code in the area prohibits all building several hundred meters from the beach and a belt of 5 to 7 kilometers is limited in economical activities (Povilanskas n.a.).

Natural and soft means of coastal protection provide good results

In **Estonia** coastal erosion was extensive, but mainly occurred on uninhabited beaches, thus lowering the expenses. A study group led by Are Kont (Kont et. al. 2006) found out, that the effect of extreme storms as the one in January 2005 can topple many times that of normal storms. In this case, the combination of lack of sea-ice, unusually high sea-levels and the intensive storm surge created perfect conditions for the wave action to hit the coastal areas at full force. The high sea-level enabled for the energy of the waves to hit coastal stretches even beyond their landward boundaries (Kont et. al. 2006).

The coastal zone hit, mainly on Saaremaa island and around Pärnu bay, is not densely populated however, and the reformation of coastline, largely similar to those of Isle of Sylt and Hel peninsula, was seen as a natural phenomenon. In many places the beaches receded tens of meters, and the beach scarps were extensively eroded, falling trees growing on their edges. This affected some NATURA areas as well, decreasing the area of mature pine forests in Pedassaar island (Kont et. al. 2006).

The only direct effect of wave action to human settlements in Estonia occurred on Valgeranna beach, where camping site buildings were destroyed. The reason for this was seen by Kont et.

al. (2006) being that the beach had already eroded before the storm, mainly as a result of the last powerful storm of 1999, and thus left without any protection from foredunes. According to Kont et. al. (2006), the situation in Valgeranna clearly shows the vitalization of shore processes measured worldwide.

Lessons of Gudrun on coastal erosion and tourism:
Climate change and human action enforce coastal erosion on the coasts of Baltic Sea

Human activity tends to conflict with the natural processes taking place on the Baltic coastal areas. In many places maintaining the recreational value of coastal areas is increasingly expensive. Hard means to halt natural erosion often lead to problems elsewhere. Soft methods such as reinforcing foredunes mechanically or with planted vegetation seem to work better. Extreme weather events account for most of the coastal processes, with the effect of severe storms like the one in January 2005 many times exceeding that of normal storms. The fact that winter storms tend to come paired in the Baltic Sea region enhances their effects. Vitalization of shore processes has been measured worldwide. Based on the material collected under ASTRA, this seems to be related to the intensity of severe storms having been on the rise during past decades. Lack of sea-ice during mild winters makes the effects of storms more severe. The changing climate could thus bring more problems for the southern Baltic Sea's sandy coasts in the future.

3.4.3 Flooding

Analysis of the data provided by ASTRA project partners showed that Gudrun caused floods in Denmark, Estonia, Finland, Lithuania, Poland and Sweden. As with the coastal erosion processes discussed before, the fluctuations of the sea-level are as such a natural phenomenon. In this case however, the swelling reached levels that caused serious human and economic losses.

Figure 9: Flooding in Pärnu, Estonia (Photo: Sten Suuroja)

Several climatic conditions favouring the development of an exceptionally high sea level took place on the January 9th 2005. As in Helsinki, too, the sea level on the coast of **Estonia** was some 70 cm above normal. This was a result of strong cyclonic activity at the time, perhaps a result of abnormally high temperatures that added to the difference in temperatures between the warm southern air masses and the cold polar air. Cyclones had passed Estonia on the 2nd, 5th and 7th of January, and set the water masses in the Baltic Sea in a pendulum-motion. Should this sea level disturbance resonate with the water masses pressed ahead of the approaching cyclone, the two phenomena amplify each other. This is what happened actually, with the effect being stronger still in the smaller Gulf of Riga basin. In addition to this, the Baltic Sea basin was filled with water flowing in through the Danish Straits (Suursaar et. al. 2006).

Sea-surges possess a risk on coastal dwellings

The maximum sea levels in Estonia were reached in Pärnu, +275 cm on the morning of the 9th. In Pärnu this meant a maximum sea-line recession of 1 kilometer (Suursaar et. al. 2006)! The northerly track of the cyclone was just about worst possible, as the trajectories of the strongest winds matched with the orientation of the Pärnu, Haapsalu and Matsalu Bays. This raised the sea level even higher. In addition to all this, the complex flow patterns of the Estonian archipelago prolonged the extreme event. In Tallinn, the water level reached a record of 152 cm some 6 hours prior to the maximum heights measured in Helsinki. (Suursaar et. al. 2006).

Following the flood, 775 houses were affected in Pärnu alone. Sadly, only 1/3 of the house-owners had insurance policies. Total property damages in Estonia were over 9 mio EUR (Kont et. al. 2006). In addition to this, the floodwaters and falling trees destroyed almost 300 cars, heaps of movables, products of various kinds, agricultural equipment and forage, outdoor equipment and firewood stocks raising the total direct damages in Estonia up to almost 48 mio EUR, over 0.6% of the country’s GNI. The areas most affected are those around Pärnu Bay (Kont et. al. 2006).

High water level caused by storm surges threatens historical centres

During the January 2005 storm, the highest wind speeds measured in **Finland** were recorded in Lemland and Rauma, averaging some 24 m/s in the afternoon of the 9th January. The gusts were reported to blow with speeds up to 30 m/s (Ilmatieteen laitos 2005). The most severe storm measured during winter 2004/05 still remained 'Rafael’ (or ‘Finn' in Sweden and Norway) that covered whole Finland on the 22nd-23rd of December 2004 (Ilmatieteen laitos 2005).

Finnish officials were informed in the evening of Thursday the 7th on the possible record-high sea levels. The warning stated by the Finnish Institute of Marine Research proved to be accurate, with water level reaching a record of +151 cm at around noon on the 9th of January. Today, the lowest construction level in Helsinki is set in adequate 3 meters above sea-level. Old dwellings, including the historical centre (including the Market square and Presidential palace), are low-lying however and very hard to protect against floods. The situation is not unlike that of many sites around the Baltic Sea, such as the old town of Stockholm.

Although the water level was record high in Helsinki, severe damages were avoided, partly thanks to the warning issued by the Finnish Institute of Marine Research and the preventive work done by the City of Helsinki rescue services. The flood threatened the historical centre however and in many places the water rose to built areas. It also caused potential disaster situations in the ever increasing underground spaces of the city, such as the multi-utility and metro tunnels (Lilja 2005). All outlet pipes of the sewage system in Helsinki had to be manually blocked in order to keep the sea water from flowing into the system. A water treatment plant in which all waste water handling in Helsinki is concentrated was flooded, forcing the officials to release some 63 000 m^3 of sewage water untreated to the sea.

In Finland, the cost to both public and private sectors adds up to a total of 15-20 mio EUR, probably closer to 20, according to the Federation of Finnish insurance companies. Damages were mainly related to the seawater flowing to cellars and harm done to summer houses. A large amount of the damages relates to Turku harbour, where several hundreds of freshly imported cars got destroyed as harbour storage areas flooded. In Loviisa, the rising water level threatened the functioning of the cooling water system in the nuclear power plant. Should the water have risen any higher, the unit would have had to shut down.

Lessons of Gudrun on coastal flooding:
Storm surges are indirect impacts of winter storms on the Baltic sea

If meteorological processes coincide right, storm surges can raise the sea level considerably on the coasts of the Baltic sea. Even with the storm being very weak as it crossed Finland, the sea-level rise had a big impact on the coastal areas. In places the effects were totally unexpected. In others some preventive means could be taken, lowering the damages. Protecting old developments is hard however, if the water level reaches record heights as it did in January 2005. New coastal developments and underground constructions on coastal areas unavoidably increase potential damages, if possible (temporary) changes in sea-level are not taken in account when planning land use on coastal areas. In places geographical characteristics may increase vulnerability. As learned in connection to coastal processes, the river-sea interaction at times enhances the sea-level rise, like in the Gulf of Riga. Increased precipitation and enhanced storm activity as a result of climate change could enhance the coastal flooding in the future.

3.5 Economic losses

The analysis of insured losses, number of properties affected, power and communications cuts, estimated indirect costs to industry, number of farm animals killed, costs of response measures taken, as well as other costs gave a possibility to evaluate the impact of Gudrun from economical point of view.

The highest **insured** costs not distinguishing between public and private sectors were reported by (in million EUR):

Denmark	617	Sweden	444
Germany	150	Finland	20

In terms of insured losses the storm stays second to the series of storms that hit Central Europe in 1999, with a cost totalling 9 billion EUR (Munich Re 2002). It is important to note that insured costs reported by Estonia, Latvia, Lithuania and Poland were much lower than those reported by the Western European countries. This can be explained by the lack of insurance traditions in the new Member States. On one hand it is not obligatory to insure public property, while on the other hand, the rate of insured private property is low as well due to lower incomes of population. Such differences in amounts of insured property imply big differences in capacity to recover, a major element in social vulnerability of different populations.

Reported **overall cost**s are as follows (in million EUR):

Sweden 2 300	Latvia 192
Estonia 48	Finland 20
Lithuania 15	Poland 0,002

This said, the damages of the storm were hard to overcome even by the old member states. Sweden too had to apply for financial support from the European Union Solidarity Fund (EUSF), a special fund created in 2002 to assist Member states and acceding countries faced with major disasters in their ‚most urgent needs' in terms of recovering efforts (European Commission 2006a)[2]. The fund was actually created following a major disaster, the August 2002 floods in Central Europe (European Commission 2006b). For comparison, the total cost of the floods of 2002 was soon after the event thought to exceed 15 billion EUR (European Commission 2002).

This time the amount supplemented was nearly 93 mio EUR, of which vast majority (82 mio EUR) was granted for Sweden. In Commissions estimates the total damages in Southern Sweden total a staggering 2.3 billion EUR, making it the county's worst natural disaster in modern time (European Commission 2006a). This adds up to nearly 0.8% of Sweden's GDP at market prices of 287977.4 mio EUR in 2005 (Eurostat 2005). In Lithuania, total damages were estimated by the EU to be approximately 15 mio EUR (slightly over 0.07% of GDP of 20587.3 mio EUR). For this, little under 400 000 EUR was granted from the fund (European Commission 2006c). In Latvia, the damage was put at 192 mio EUR (1,5% of GDP of 12789.1 in 2005), of which 9.5 mio was covered by the fund (European Commission 2006d). Estonia's share was 1.3 mio EUR, towards damages totalling almost 48 mio EUR and GDP of 10540.2 mio EUR (0,46%) (Kont et. al. 2006). For comparison, the cost of the storm in Finland was about 20 mio EUR, 0,01% of the GDP in 2005 (Eurostat 2005).

Depending on the impacts, the total costs vary from 2400 EUR in Poland to 2.3 billion EUR in Sweden. In all, total cost of the storm (including damages in the UK) is estimated at 2.42 billion EUR (3.03 billion dollars) by Swiss Re, out of which 1.6 billion EUR was insured. This made it the 40th costliest insurance loss since 1970 (Swiss Re 2006).

Main economic sectors suffered from the storm can be distinguished as being the following (division according to The Finnish National strategy on adaptation to Climate Change (MMM 2005)):

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[2] European Union Solidarity Fund (EUSF) provides help for immediate recovery means after major catastropheps, in priciple limited to non-insurable damages. The preconditions for EUSF funding are as follows: "- In the event of major natural disaster, considered as such if the estimated cost of the direct damage is over EUR 3 billion (2002 prices) or 0.6% of the gross domestic product of the State in question. By way of exception, a neighbouring Member State or accession country that is affected by the same disaster can also receive aid, even if the amount of damage does not reach the threshold.
- Exceptionally, in the event of an extraordinary regional disaster that affects the majority of the population of a region and has serious and lasting effects on its economic stability and living conditions. Special attention is given to outlying or isolated regions."
Source: European Commission, Inforegio. http://ec.europa.eu/comm/regional_policy/funds/solidar/solid_en.htm

1) Exploitation of natural resources (Forestry, agriculture and fisheries)
2) Energy
3) Transport and Communications
4) Spatial development

These are to be covered in more detail in the following chapters.

3.5.1 Forestry and agriculture

The effects of storms on forestry are multiple, as they not only destroy the forests in prime growing age but also put a heavy load on the timber markets, although with timber of variable quality. For agriculture, providing farms with spare power is a key factor.

Reforestation only one part of the cost in case of storms

Estonian case study (Kont et. al. 2006) offers a good example on the sources of expenses considering forest damages; Total damages to Estonian forests total almost 8 mio EUR, of which 3.2 mio EUR regarded state-owned forests. The damages for state-owned forests can be divided as follows (According to Kont et. al. 2006):

955 000 EUR	Additional cost of harvesting the fallen trees
1 420 000 EUR	Revenues lost as the prise for timber falls as markets are overcharged
620 000 EUR	For reforestation of totally damaged areas of 1258 ha
80 000 EUR	Cost of restoring the infrastructure related to forest management
145 000 EUR	cost of aero surveillance and inventory

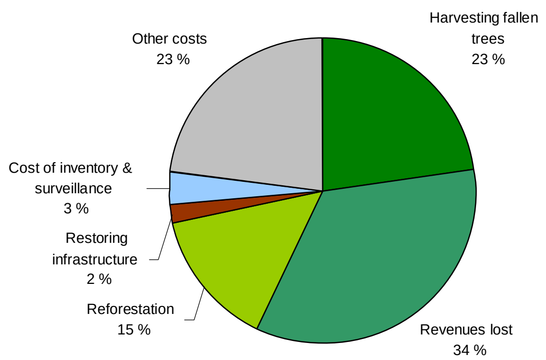

Figure 10: Winter storm Gudrun: Damages to state-owned forests in Estonia (total 3.2 mio EUR)

In Sweden, the reforestation costs were counted to be over three times more expensive at 1650 EUR per hectare for spruce and up to 4400 EUR for leafy trees, adding to a total of estimated 240-725 mio EUR for planting the destroyed 160 000 hectares (Palmér 2005). Several means are available to cut the costs, like planting fewer spruces and letting the natural growth of leafy trees fill the gaps. This adds to the cost however through diminished timber production compared to the normal methods (Palmér 2005).

More than a year after the storm, in February 2006, some 10-15 % of the fallen timber still waits to be handled (Skogsstyrelsen 2006). The total cost in Sweden was put in order of 2 billion EUR, with additional costs possible as a result of damages cost by insects on the remaining trees, the threat of insects made worse because of the long storage time for the timber over summer (Bäcke et. al. 2005). It was even announced, that the risk of forest fires had risen considerably, because of the amount of dried timber in the forests and because of the number of clearing machines that could possibly set the fires going was very high (Skogsstyrelsen 2005).

What is worth noting is that the excess of timber actually came as a welcomed surprise to the Finnish forestry sector. When the storm arrived in Finland, it had actually already weakened to the extent that no direct damages were reported. The mild winter (that actually may have enhanced the wind damages elsewhere as the soil frost normally anchors the trees to the ground) however hindered efficient harvesting, as heavy machinery in these circumstances would have damaged the roots of the trees intended to be left growing. Some sawmills were already suffering from lack of supply at the time of the storm (HS 2005).

Protecting farms from power cuts critical in limiting damages to agriculture

According to our questionnaire, the storm caused the death of 11 253 domestic animals and birds in **Latvia** (8 cows, 140 pigs and piglets, 8882 hen and chickens, 31 deer and stags and 169 beehives of bees) and 6 in **Lithuania**. Farmers in **Denmark** could not milk cows due to the power cuts. Although the impact of the storm was very big in **Sweden**, no farm animals or birds got killed. According to Swedish legislation, a spare power generator has to be installed on every farm. This helps to avoid negative impacts in the case of storm. However, despite of back-up generators being available the problems met in Denmark also applied to **Estonia**. It was noted, that even the milk milked was lost because of refrigerating problems. 200 animals (mainly lambs) were left dead in Estonia. A share of cattle food was lost because of floods (Kont et. al. 2006).

Fisheries escaped largely unharmed

Approximately 20 000 EUR were counted as fishery losses in the Curonian Lagoon (**Lithuania**). In **Estonia**, the value of equipment damaged that related to fishing industry was 0.278 mio EUR (Kont et. al. 2005).

Lessons of Gudrun on forestry and agriculture:
Storms' effects reach far from instant wind damages

Although the fallen trees are the most visible reminder of the cost of a storm event, harvesting the fallen timber is only the starting point of storm damages. Apart from the unavoidable cost of clearing up and replanting the forests felled by storm winds, many cumulative factors increase the cost of replanting; First, the felled areas have to be surveyed. To avoid insect damages, the trees should be harvested as soon as possible, preferably before the summer. This adds to the cost of normal harvesting. The excess amount of dry timber in the forest increases risk of forest fires. Large amounts of timber on the market, although of poor quality, decrease the timber price per cubic meter. On top of this, the growing cycle has to be started anew, and it takes decades before the trees reach their prime growing age again. In agriculture and fishery industries, losses in production add to the direct cost of damages to animals, infrastructure and habitats.

3.5.2 Energy production

One of the main negative effects of Gudrun were power and communication cuts. About 100 000 households had power cuts in Denmark and Estonia. About 30 000 km of power lines were damaged in Sweden. The power cut-offs influenced some 60 % of the territory of Latvia, and approximately 400 000 (about 40 %) electricity customers were left without electricity in the immediate aftermath of the storm. In Lithuania about 230 000 residents were temporarily left without electricity. In many analyzed countries the communications cuts were observed. For example, in Latvia power-cuts caused damages in telecommunication for about 4 500 clients of Lattelekom. Approximately 330 km of overhead lines were damaged and ~1400 posts were broken off.

Strong winds stall wind farms in Denmark

In **Denmark**, that first experienced the effects of the storm, the struggle started towards the afternoon of January 8th. Main worry seems to have been the faith of the country's wind energy production and whether the some 5400 wind turbines in Denmark would stand the storm. As wind speed rose above 25 m/s on a broad front in whole of western Denmark, most of the circa 4000 turbines operated by the local electricity provider Eltra automatically shut down. This reduced the amount of energy produced locally to less than 1/20 of the full capacity of total 2 380 MW. This power demand was filled with regulating power bought abroad – but not without difficulties, as the storm started to affect energy production on a wide area in Northern Europe (Andersen 2006, EnergiNet.dk 2005).

In all, the main transmission grid met with only few damages and the public was not affected by power cuts. Low-voltage overhead cables were hit however, and this had an impact on some 150 000 customers (Andersen 2006). Thanks to a scrapping policy and renewal of old wind turbines in Denmark, none of them was harmed (EnergiNet.dk 2006). Many of them had to be started manually on site, slowing down the recovering process despite the winds calming down to optimal production speeds (Bülow 2006). Some hundreds of customers of Eltra's were still without electricity on the 11th of January (Andersen 2006).

Nuclear energy production in trouble in Sweden

In **Sweden** the power cuts affected 730 000 people. Half of them got electricity back within a day, but in total the ‚power-cut days' were counted to add up to 2.3 million. This had a cost of 274 mio EUR (KBM 2005). The single most notable event was forced closing down of four nuclear reactors and considerable downscaling of fifth (WNA 2005). The reactors in Barseback and Ringhals encountered problems with the wind, it for example blowing excess amounts of salty water on the power plant switchboards and hammering the cables. Together, these reactors account for a fifth of all energy production in Sweden (Ringhals 2005).

The main problem in Sweden were the uprooted or broken trees that harmed some 30 000 km's of electricity lines. Thanks to the mild weather no-one was harmed because of the breaks, although tens of thousands of people were still without electricity more than a week after the storm (KBM 2005).

Both personnel and spare parts ran out as the havoc was cleared and had to be called and ordered from abroad. Some of them such as the cables ran totally out, and had to be delivered to the affected areas straight from the factories. A problem specific to Sweden was the massive amount of fallen trees, that both cut access to the affected sites especially on small forest roads and also demanded for the electric lines to be cleared before setting up the lines. In some places the new cables were just spread over the fallen trees, and tree stumps were used as improvised poles to get the electricity back on as quickly as possible (Pärnerteg 2005).

As said, the **Finnish** nuclear units at Loviisa encountered problems as well. The rising water level came very close to effectively enable the power plant's cooling system, which would have led to closing of the plant (WNA 2005). Although not really threatening events, the examples of Sweden, Finland and Denmark can be seen as signs of the problems of unilateral energy production. In a case of extreme weather event, as normal means of energy production fail, acquiring the capacity needed from abroad may be hard, as was seen in Denmark.

Storm damages especially high on low-voltage lines

In **Lithuania** the energy network almost collapsed on Saturday night, leaving 1, 4 million people without electricity (SMHI 2005). The main reason for power cuts were trees fallen on power lines, but one high-voltage line post collapsed too. The repairs seem to have been quick though, the defect on main lines mainly temporary reducing the reliability of the grid. These damages were repaired by 15th January (Trakšelienė 2005, Lietuvos Energija 2005).

The effects were very severe in **Latvia**. 54 000 km's of distribution lines were damaged, leading to a 23-day long emergency situation. The main reason for this were trees fallen on lines, but 3 transmission line towers collapsed and 34 were damaged, too. What resulted was ‚the largest mobilisation ever in the Latvian electricity business' (Latvenergo n.a.). Some 6000 people worked on clearance and repairing activities, first restoring the power to priority customers like schools and hospitals. According to our inquiries, about 20 000 companies were left without electricity. A cost of 4.7 mio EUR followed (Latvenergo n.a.).

Returning energy supply for remote areas slow

Figure 11 nicely demonstrates the situation, in which power can be restored to a majority of the customers rather quickly after the storm. The further the customers are located from the main centres however, the slower the reparation work gets (likely because of large distances affecting the reachability and increasing the number of damages on the lines) (according to Latvenergo, n.a.). The same situation persisted in Sweden, where trees fallen on roads slowed down the reparations. Naturally, the main road network was soon opened but clearing up the less important roads took days.

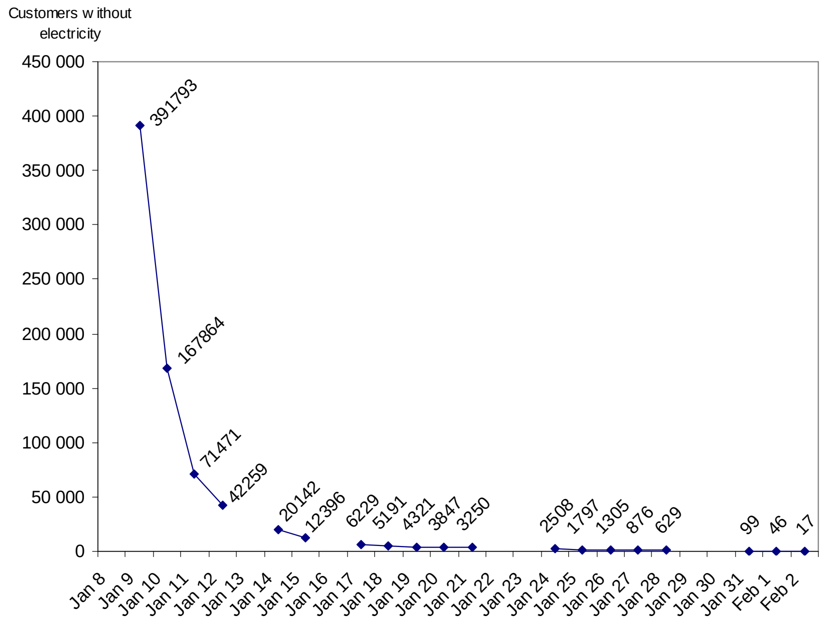

Figure 11. Latvenergo customers without electricity by day after Gudrun (Latvenergo n.a.)

Electricity cuts affected some 15 % of households in **Estonia**, as several hundred substations were damaged by the storm. Electricity poles got broken, too. Together with temporary power supplies needed the cost caused by these was almost 3 mio EUR (Kont et. al. 2006).

Warm weather unfortunate to forests, blessing for people

To sum it up, the damage caused to energy networks was substantial. Fallen trees seem to be the most critical factor in the durability of the network. In Latvia it was estimated, that the electricity lines could be made less vulnerable by cutting trees within 20-30 meters from the lines (Latvenergo n.a.). This must mean the low-voltage distribution lines. In Finland, the main transmission system lines are cut to width of 26-30 meters for 110 kW lines and 0ver 40 meters for 400 kW lines, with additional border area where the trees are kept shorter (Fingrid 2006). The effects of the storm to the public might have been greater, should the weather have been colder – on the other hand ground frost could have prevented some trees from falling. It is hard to see how the effects could have been handled more efficiently though, as the sheer number of fallen trees greatly slowed the repair work down.

Lessons of Gudrun on energy sector: Extreme weather events can cause nationwide impacts on energy production and transmission

Effects of extreme events can be felt even on national level. In case of countries being in a large extent dependant on some forms of energy production, such as wind power in Denmark and nuclear Power in Sweden, unfavourable weather conditions can be problematic. As in January 2005, weather disturbances often affect large areas, making it harder to compensate the energy needed with imports from abroad. Trees fallen on low-voltage distribution lines often cause most of the power cuts. Fallen trees form obstacles on the roads and electricity lines that can greatly slow down the means of recovery. After Gudrun power was in most places restored in a couple of days however. Warm weather helped to avoid serious consequences to human populations.

3.5.3 Transport and communications

In many countries (Denmark, Sweden, Lithuania, Estonia, etc.) a big negative effect on land, water and air traffic, as well as tourism infrastructure was observed. A critical effect were the communication cuts that impeded the work of rescue and clearance teams.

Damage to state owned highways in Estonia (Road Administration data) amounted 729 814 EUR. Other damage to the roads, streets, street lighting, culverts and cleaning of fallen trees from the roads made up 870 808 EUR.

In Finland the effects were minor. During the storm, all major ferry operators cancelled some ferry departures. On land, the Finnish Road Administration traffic services reported poor driving conditions. The storm did not affect rail traffic or flights from Helsinki-Vantaa airport, according to state railways (VR) and Finnair.

Figure 12: Flooding streets in Helsinki (Photo: Samuli Lehtonen)

3.5.4 Spatial development

Threats posed by extreme weather events on spatial development are manifold. In the case of Gudrun they depend on the impact the storm had on local natural systems, being mainly related to flooding and enhanced coastal processes. These are the most straightforward effects that threaten the built environment and people inhabiting coastal areas, if not taken into account in coastal planning.

A thorough study about the effects of climate change on urban areas and on the possibilities for adaptation through urban planning was recently compiled by CURS, as part of the FINADAPT –project. The study, titled ‚The challenge of climate change adaptation in urban planning' (Peltonen et. al. 2005) can be found at http://www.ymparisto.fi/default.asp?contentid=165344&lan=en.

4. Measures taken in the Baltic Sea Region before, during and after Gudrun

Taking into consideration the variable impacts Gudrun had on the national and local/regional level, different measures were implemented in the BSR countries and case study areas before and after the storm. Preparedness efforts and early warning systems functioned differently in the countries in study area. Following parts of the report provide an overview of such measures.

The analysis of measures implemented before and after Gudrun at local and regional level shows that in many cases the storm prompted various local activities to improve preparedness and reduce vulnerability. As such, it served as a "focusing event" for developments in local planning and policy measures.

4.1 Early warnings and preventive action in the countries surrounding the Baltic Sea

4.1.1 Automatism and adaptation in use in Denmark

Denmark was the first country to be hit by the storm. According to our study, relatively quick response and first storm warning was given out by Danish Meteorological Institute (DMI) at 12:23 UTC (13:23 local time) on January 8. The DMI arranged beforehand that authorities knew about the potential impact of the storm to be prepared for the worst case. As the wind speed increased, wind turbines automatically shut down and turned their blades to minimise the surface meeting the wind (Bülow 2006).

The Danish meteorologists now apply a 5 km grid model covering the North Sea, the Baltic Sea, the British Islands and Iceland. It has also been used to recalculate the winter storm. Their larger simulation area is running with a 15 x 15 km grid, area covers whole Europe, the North Atlantic, the Arctic region, North America. There exists a national Stormcouncil (Stormrådet) that remedies in case of storm surges. After the storm the Danish Meteorological Institute started retrospective analysis of the storm.

Danish Flood Insurance Pool has covered flood losses since 1991. In 2001, the Danish government introduced a bill on storm surges and storm losses, an amendment to the Storm Flood Act telling it being applicable for storm damages, too (MIM 2006). Simultaneously, a storm council (Stormrådet) was established – if the Ministry of Environment calls it up, this council can decide if according to the law financial support from the Danish state is granted for private forest owners. In addition, a forest counselling organ was established (skovrådet). The support given covers for clearing the affected forests and replanting them with sturdy tree species (MIM 2006).

4.1.2 Dissemination an issue in Sweden

Swedish meteorological institute SMHI made weather forecasts, that proved to be accurate and laid out early enough (SMHI 2005). It was however found that getting this information to the masses is hard because of the volume of 'background media-noise'. The need for information is vast however when the event is on, so means of developing information sharing are being thought of. A list of recipients on both regional and municipal level should be come up to keep up to date on the event.

Regarding forest management in Sweden it was learnt that there were no strict recommendations how to minimize the vulnerability for damages. Most forest owners are aware of the risks but very few plan their forestry practices to minimize the risks. It can be argued that forestry measures exacerbate potential storm damages. Regarding the energy supply there are several examples of measures to prevent storm damages such as broadening of power line routes, power lines placed underground, building more robust power line systems. There was also a well performing emergency organization prepared to work with all problems caused by the storm. Energy companies have gathered in an organization together with power grid owner Svenska kraftnät to cooperate when a disaster takes place.

According to a new law (2003) about the responsibility of the municipalities at extraordinary events, most municipalities were prepared having plans and an organization settled down and ready to act during acute crisis. Many of the municipalities had done risk– and vulnerability assessments. The county boards regularly perform exercises that made them prepared on what to do. Some of them also have information systems for crisis. It was seen that municipalities acted relatively well together considering the disturbances in the telecommunications. Co-operation between regions should still be enhanced, as well as with sectoral governance.

Farms in Sweden are already provided with spare power sources in case of storms. This helped to minimize the damage. Because of trees fallen over roadways, the first task in order to fix the electricity and telecommunications networks was to clear up the access roads. This had to be done by harvesters, and was slow. The main road network was cleared in 6 days following the storm. During and after the storm, teleoperators installed spare aggregates to provide with power to keep the network in operation. It seems that these in many cases could not withstand the continuous use however, but stalled or had to be maintained repeatedly. Information exchange between the electricity and telecommunications providers was also seen inadequate.

4.1.3 Storm passes Germany

Apart from the coastal erosion on Sylt, Germany was left unharmed by the storm. Preventive actions were thus not necessary.

4.1.4 Poland on alert – escapes unharmed

It was known that storm is not going to be a serious threat to **polish** coast so no special activities or countermeasures were taken before it. First information about the storm comes from IMGW - Instytut Meteorologii i Gospodarki Wodnej (Institute of Meteorology and Water Management). If threats are serious then next alert comes from Voivodeship Flood

Committee and Marine Office VTS, which is the Centre of Marine Hazards. In case of January storm and its influence to land areas, communicate from IMGW was enough.
In case of unpredictable events, Marine Office is always prepared to take action. There are several storehouses with bags, sand and shovels always in readiness.

No problems occurred except lack of information from private owners of few affected camping sites situated close to the shore. The documentation of Winter Storm damages was done in a proper way, as it is an obligatory duty of Marine Office.

Nothing was done before the storm in **Gdansk**, as the storm was not a threat to Tricity coast. As it was mentioned in previous parts of the report, in case of unpredictable events, Marine Office is always prepared to take actions. There are several storehouses with bags, sand and shovels always in readiness. Taking into account that there were no impacts of Gudrun in Gdansk, no measures were implemented after the storm.

4.1.5 Lithuania on watch

The Lithuanian Hydrometeorological Service and its Klaipeda Division issued the early warning (dated 10:52 UTC, 12:52 local time, Jan 8, 2005), but only for Lithuanian coastal region and coastal waters (Klaipeda port, Baltic Sea and Curonian Lagoon). It stated that for the next 12-15 hours a probable storm would prevail, with gusty SW wind and water level increase up to 110-130 cm. Also 5, 4, 3, 2 and 1 day lead time weather forecasts were issued, where max SW wind strength (m/s) was predicted respectively being 20, 22, 25, 27 and 30.

In **Klaipeda and Curonian Spit** the measures implemented before and after the storm were closely coordinated with measures implemented at national level.

4.1.6 Sea-level rise surprises Estonian officials

In Estonia Estonian Meteorological and Hydrological Institute ensured sufficient early hurricane warning. Hurricane warnings were provided in various media channels 1-1.5 days prior to the event. However, although individual scientists provided unofficial warnings of up to 2.4 m sea level rise, no official storm surge warnings were available and almost no adequate measures against possible sea level rise were implemented. Thus a crisis committee gathered in Pärnu only after the storm surge began. During the storm, evacuation of people from flooded areas was organized. After the storm various mitigation and repairing actions, documentation of losses, analysis of lessons learnt, broad national discussion on warning responsibilities and insurance issues ensued.

Tallinn was more prepared for the storm. Storm alert was given; Rescue Board was ready to take actions; A Crisis Committee gathered. As there was no impact of storm in Tallinn, no measures were taken.

4.1.7 Finland prepared for sea-water floods

Thanks to the December 2004 storm the authorities of Finland were perhaps somewhat more alert in January than normally. As the storm moved closer, the Ministry of Internal Affairs, briefed by the personnel at Finnish institute of Maritime Research, as early as 13:50 UTC (15:50 local time) on Friday the 7th issued alerts and additional information to the coastguards on the Gulf of Finland and in Western Finland, the Finnish Maritime Administration and the City of Helsinki Rescue Department.

In the first alerts, the severity of the storm was still considered to be quite low, and on reflection, quite close to the strengths actually measured. However, some signs of record high sea levels were already observed, and a warning of unusually high waves in the Baltic Sea was issued. Unlike in Estonia, the City of Helsinki Rescue Department started to take action immediately after being informed of the threat. Based on the very accurate estimate of water height of 1,5 meters above normal, all the potential points of damage were mapped. Although this can be seen coming a bit late, the extra day given by the early prognosis was adequate to get a good picture of potential damage.

Helsinki has a special Rescue service Advisory Board that brings together officials from the rescue services, the police, emergency services and Finnish Defence forces, as well as from municipal offices and private companies such as City of Helsinki Public works department and Helsinki Water. Part of this team was briefed on Friday night, and on Saturday morning the group was gathered to decide on tasks on preparation for the storm (Lilja 2005).

At this point on Friday the ship-owners, who seem to operate quite freely based on their own judgment, were merely monitoring the situation and left the decision of whether to follow the schedule to the captains of the ferries. However, by 5 o'clock the following morning the situation was regarded in a somewhat worse light, and the Finnish Maritime Administration advised the smaller boats to stay in harbour.

The wind was also seen as a threat on coastal land areas, and the City of Helsinki Rescue Department asked dwellers to keep alert and stay indoors. This was due to the risk of getting hit by flying debris and the danger caused by falling trees. The City of Helsinki Rescue Department undertook some innovative approaches in protecting the Kauppatori area in front of the presidential palace, as they set up a wall made of cubes of recycled paper with some aid from the Finnish Defence Forces. The staff of the Presidential palace stayed on the alert in case of flood throughout the weekend.

At the same time, Helsinki Water did some precautionary work to keep seawater out of the sewage system and eventually from the premises it serves. The Finnish Environment Institute stated that the estuaries and lakes in southern Finland might be affected by flooding.

In **Espoo** a work group was formed to plan protection measures for future storms and floods. In Loviisa (Itä-Uusimaa region) a flood dike was constructed during storm and there will probably be a follow up done after storm. In other case study areas the storm had minor or no effects.

Lessons of Gudrun on adaptive planning for extreme weather events:
Early warnings greatly help to overcome the impacts of winter storms

A warning of the storm issued in time by the meteorological offices helped in most countries covered to lessen the damages. The effects of the storm surge can be prevented to some extent, if the areas most vulnerable are known. Even a warning issued a day in advance helps, if a rescue organisation with defined tasks and communication networks exists. Some damages like the impacts on forests are unavoidable in terms of short term adaptive means. Planning for the storms (deciding for sturdy tree species etc.) greatly helps. In some countries this is taken up as a part of the means to overcome the storm damages. For short term interruptions emergency means such as compulsory units of spare power on farms are useful. As the emergency situation persists however, it was seen during Gudrun that these temporary means tend to work less perfectly and slow down the actions to clear up the damage. Communication between actors is one of the key priorities in storm situations.

4.2 Improvements and changes taken after the storm

Based on our study, Gudrun stimulated technical improvements, as well as organizational and institutional changes in almost all countries analyzed in this report.

A number of improvements were implemented in **Sweden**. Swedish Meteorological and Hydrological Institute have a meteorological warning system that is freely accessible, and offers a good prognosis of storm wind speed and track 24 h ahead; commercial weather service for enterprises concerning risk of weather events is available as well. Main problems in organizational issues were seen in unclear crisis organizations and in the information collected by the governmental offices. It was seen that information should be collected centrally, to spare the efforts made by individual regional and municipal offices.

Information collection and sharing found crucial

Investigations have been started after the storm to find out how to become prepared to use help from other countries during events like the storm in the future. Projects have been started to make the 112-system more robust. A plan of action to improve the information and communication during crisis has also been started. A joint radio communication system for the police, the rescue service the ambulance– and acute medical care will be built up in southern Sweden. Information on how forest owners can cope with the damages and reduce the risk is collected in Swedish on the Swedish forest agency’s webpage (Skogsstyrelsen 2006b).

In Stockholm county Electricity supply rules have been changed after the storm. The most relevant changes are a) Requirement that electricity network must not be longer than 24 h; b) Power enterprises have to reimburse clients (if electricity power is not delivered within 24 h after an event), c) Conducting risk and vulnerability analysis and d) Better information to clients.

Coordination between actors needed

Definite technical improvements have been made in **Latvia** in the sectors where the shortages were observed and reported. Shortly after the winter storm event several generators were purchased to provide storm supply in the case of power cuts in most critical sectors. The Department of the Strategy at the Ministry of the Interior made several suggestions how to improve the institutional system and to solve problems caused by natural hazards:

1) To improve the coordination between state institutions and local municipalities, there is an evident need to declare responsibilities of each institution in the case of natural hazards.
2) The need has been revealed to include resources allocated in the budget planning process as reserve funding that would be available in the case of storms, flooding and similar hazards. It was suggested that allocation of these resources needed primary for institutions directly responsible for emergency situations. The need to develop a system of public training and education in the area of civil defence has been listed.
3) The need to study possible threats of storms, natural hazards and to increase applied research to develop the optimal system of hazard mitigation have been underlined.
4) There is an evident need to improve work in hazard identification within the Latvian Environment, Geology and Meteorology Agency.

As always after storm events, The Polish Marine Institute investigated most affected areas in **Poland**. Losses were measured and documented. There were some biotechnical activities concerning strengthening the shore, e.g. placing brushes in most affected and vulnerable spots.

Coastal monitoring, preventive protection and identifying vulnerable spots important

From 1993 onwards coastal monitoring is carried out every year in **Lithuania**. Cross-section of the coastal levelling has been made. After the winter storm of 2005 (on January 15) coastal monitoring was carried out here, too. During the monitoring exercise, coastal erosion scale was calculated. Preventive protection of the special objects, management of storm affected areas and supply of beaches with the new sand was organized. It was noted that the in 2004 reconstructed northern mole of the Klaipeda port highly reduced storm impact to port activity.

In **Estonia** an agreement was established between the weather forecast institution (EMHI) and the marine scientists from the Institute of Marine Systems for better communication.

Means of flood mitigation are being thought of or tested in Helsinki, **Finland**. In Espoo a flood group was established to study means of adaptation. The Real Estate Department of the City of Helsinki still does not see sea-level rise as a major problem in Helsinki in general, although they agreed on it being a real problem for some low-lying areas. The City Council of Helsinki pondered upon taking floods as an issue in their new detailed plans. This view was shared by officers in charge of the planning and building permits at city and communal level.

Lessons of Gudrun on vulnerability reduction:
Information sharing is a key activity in storm situations

In the areas most severely hit, means of enhancing communication between key actors was found to be a key priority during storm situations. Communication systems have been integrated and made more robust following Gudrun. It was seen, that coordination between different actors on different levels should be re-thought. Information of the effects of the storm at stake should be collected centrally and distributed further to persons or institutions at stake. In this sense, the Rescue services advisory board operating in Helsinki seems to be a good solution.

Some effects can be diminished with proper planning in advance, like taking into use means of forestry that would lower the vulnerability of forests towards storm damages. To minimise economical losses on coastal zones it is important to fix the damages to natural storm protections like foredunes as soon as possible. Hazard identification is a key issue in both urban and rural areas.

5. Conclusions

Winter storm Gudrun (Erwin) battered northern Europe on January 7-9, 2005. 17 persons died in the storm. Social, economical and natural systems were severely affected. Total costs were estimated being close to 2.5 billion euros. Gudrun exposed the lack of adaptation towards weather-borne hazards that already today pose a threat to the countries bordering the Baltic Sea. Climate change is expected to enhance extreme weather events that are thus likely to occur at a shorter interval in the future.

Effects of extreme weather events manifold in BSR

Flooding and evacuation of inhabitants, cuts of power and communication lines, damage of property and infrastructure, disruption of sea, air and land transport, forest losses, coastal erosion and impacts on industrial and energy sectors were named as main impacts of Gudrun in this study done under ASTRA -project. A single storm event showed impressive variability in forms of damages, depending on the local geographical characteristics and human vulnerabilities.

Flooding caused problems mainly in Finland and Estonia. It was mainly due to a storm surge driven by Gudrun, although several conditions favoured reaching the record-high water levels. In the sandy south coasts of the Baltic Sea extensive erosion was the main concern. On these coasts, extreme weather events have been found being main erosive agents. Their strength is enhanced with the lengthening of the ice-free period. It has also been seen that the number of strong storms is on the rise. Lithuania for example has experienced 10 storms previously considered as once-in-a-hundred-years events during the past 50 years!

Cuts in electricity supply influenced hundreds of thousands of people. They were mainly caused by interruptions on the main means of energy production, such as wind energy in Denmark and nuclear energy in Sweden. Because of the spatial reach of the storm compensatory energy sources could not be fully exploited. Damages on low-voltage lines hindered delivery, in remote places for weeks.

Forest losses were massive especially in Sweden. Many factors like planted monocultures, large share of shallow-rooted spruces and modern rough harvesting techniques increase the vulnerability of forests towards wind damages. Fallen trees blocked roads and cut power lines, with the first slowing down the recovery from the latter. Overall, human impact tends to strengthen the impacts of storms and increase the vulnerability of people towards extreme weather events.

Early warnings, information sharing and coordinated action are key elements in damage control; Lessons of Gudrun

Each BSR country has its own strategies or rules of behaviour and actions in extreme situations. The overview analysis showed that before Gudrun more activities were implemented at national level, while local and regional levels were more active only after the storm. Analysis of measures taken before and after the storm, as well as performance of early warning systems at national and case study levels showed that countries that had experienced storms previously were better prepared for the Gudrun and implemented measures more efficiently.

The analysis of impacts and measures taken before and after Gudrun showed that it is essential to ensure the good prediction and management of extreme weather events at both national and local levels. Lessons of Gudrun also showed that

- Adaptive capacity of BSR countries has to be increased, while the immediate rescue capacities of rescue services has to be improved.
- There is a need for a better information sharing and coordination between different actors
- Regulatory and institutional measures should be initiated to address sesources and responsibilities of institutions
- Co-operation on sectoral strategies is needed, both on public and private sectors
- Awareness on changing return periods of storms should be raised and documentation of the storm events improved

Gudrun stimulated technical improvements, as well as organizational and institutional changes in almost all countries analyzed in this report. Public information was given on damage minimization in Sweden, and technical preparedness improved in Latvia by purchasing spare power units. Some regulatory and institutional initiatives were made, like setting up a flood group in Espoo, Finland.

Importance of the Gudrun case study for the ASTRA –project is high

In terms of ASTRA –project, the example of Gudrun offers some interesting insights;

1) First, it gives a glimpse of the very varying aspects the effects of climate change can have even on a spatially very limited area such as the BSR.
2) Second, it showed some key elements in damage control and ways of reducing vulnerability towards extreme weather events. It also showed good practices in terms of adaptation policies that are to be studied further in ASTRA.
3) The study shows that extreme events can work as "booster" to improve preparedness to extreme events – both the stakeholders involved in climate change adaptation and the general public need to be reminded on the expected effects in order to engage action. This asks for some kind of strategy ready to be implemented when the next event occurs.
4) Finally, the study shows that adaptive measures can truly minimize the impact of extreme events, as shown in the study in the example of spare power generators used on Swedish farms

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The Department of Civil Security of Klaipeda county head administration (Lithuania);
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Annexes

Annex I: Questionnaire for Gudrun assessment at national level

WINTER STORM 8-9 January 2005 **IMPACTS AND RESPONSES**	AFFECTED AREA **< Add NAME of YOUR COUNTRY>**
Please send the answers to the questions in part I and part III (questions 3.1 - 3.3) before 9.12.2005. The deadline for answering the more detailed questions is 15.1.2006.	
I. WINTER STORM BASIC DATA	
1.1 Highest sea-level measured (cm). (9.12.)	
1.2 Maximum wind speed (gusts, m/s). (9.12.)	
1.3 Maximum wind speed (sustained, m/s). (9.12.)	
1.4 Specify the regions affected. (9.12.)	<Add affected regions here>
1.5 General information of the event. (9.12.)	< Add description here >
1.6 Information source(s) on storm data. (9.12.)	
II: IMPACTS	
HUMAN LOSSES	
2.1 Number of casualties	
2.2 Number of people injured	
2.3 Number of people affected	
2.4 Other human losses (specify)	< Add description here >
ECONOMIC LOSSES	

2.5 Insured losses (Euros) public sector	
2.6 Insured losses (Euros) private sector	
2.7 Number of properties affected (e.g. roof tops)	
2.8 Power cuts (number of households affected)	
2.9 Communications cuts (no of telephone clients aff.)	
2.10 Estimated indirect costs to industry (e.g. losses in production)	
2.11 Number of farm animals killed	
2.12 Costs of response measures taken	
2.13 Total cost (Euros)	
2.14 Other economic losses (please specify)	< Add description here >
NATURAL LOSSES	
2.15 Area flooded (km2)	
2.16 of which Agricultural (%)	
2.17 of which Urban (%)	
2.18 Shoreline affected (eroded etc., km's of shoreline)	
2.19 Forest losses (areal, km2)	
2.20 Forest losses (amount of timber, m3)	
2.21 Other impacts to natural areas (please specify)	< Add description here >
III. RESPONSE AND ADAPTATION MEASURES	
3.1 What measures were taken before the storm? (9.12.)	< Add description here >
3.2 What measures were taken after the storm? (9.12.)	< Add description here >
3.3 Performance of early warning systems. (9.12.)	< Add description here >
3.4 What were the main problems in response?	< Add description here >
3.5 Did documentation of winter storm damages take place	<yes/ no> <please specify>
3.6 Did the storm result in technical improvements?	<yes/ no> <please specify>
3.7 Did the storm result in organisational or institutional changes?	<yes/ no> <please specify>

Annex II: Questionnaire for Gudrun assessment at local and regional level

WINTER STORM 8-9 January 2005 IMPACTS AND RESPONSES	AFFECTED AREA <ADD NAME of CASE STUDY AREA>
Please send the answers to the questions in part I and part III (questions 3.1 - 3.3) before 9.12.2005. The deadline for answering the more detailed questions is 15.1.2006.	
I. WINTER STORM BASIC DATA	
1.1 Highest sea-level measured (cm). (9.12.)	
1.2 Maximum wind speed (gusts, m/s). (9.12.)	
1.3 Maximum wind speed (sustained, m/s). (9.12.)	
1.4 Name the locations most affected. (9.12.)	<Add affected locations here>
1.5 General information of the event. (9.12.)	< Add description here >
1.6 Information source(s) on storm data. (9.12.)	
II: IMPACTS	
HUMAN LOSSES	
2.1 Number of casualties	
2.2 Number of people injured	
2.3 Number of people affected	
2.4 Other human losses (specify)	< Add description here >
ECONOMIC LOSSES	
2.5 Insured losses (Euros) public sector	
2.6 Insured losses (Euros) private sector	
2.6 Number of properties affected (e.g. roof tops)	
2.7 Power cuts (number of households affected)	
2.8 Communications cuts (no of telephone clients aff.)	

2.9 Estimated indirect costs to industry (e.g. losses in production)	
2.10 Number of farm animals killed	
2.11 Costs of response measures taken	
2.12 Total cost (Euros)	
2.14 Other economic losses (please specify)	< Add description here >
NATURAL LOSSES	
2.15 Area flooded (km2)	
2.15 of which Agricultural (%)	
2.16 of which Urban (%)	
2.17 Main type of flood: (coastal, riverine, urban, rain related)	
2.18 Shoreline affected (eroded etc., km's of shoreline)	
2.19 Forest losses (areal, km2)	
2.20 Forest losses (amount of timber, m3)	
2.21 Other impacts to natural areas (please specify)	< Add description here >
III. RESPONSE AND ADAPTATION MEASURES	
3.1 What measures were taken before the storm? (9.12.)	< Add description here >
3.2 What measures were taken after the storm? (9.12.)	< Add description here >
3.3 Performance of early warning systems. (9.12.)	< Add description here >
3.4 What were the main problems in response?	< Add description here >
3.5 Did documentation of winter storm damages take place?	<yes/ no> <please specify>
3.6 Did the storm result in technical improvements?	<yes/ no> <please specify>
3.7 Did the storm result in organisational or institutional changes?	<yes/ no> <please specify>