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FOREST STAND CHARACTERISTICS AND WIND AND SNOW INDUCED FOREST DAMAGE IN BOREAL FOREST

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Abstract

The meteorological characteristics and the impacts of snowstorm and windstorm are studied in unmanaged and managed forest stands in boreal forest in western Finland. Specific attention is paid on tree species and susceptibility of different forest stands and location-topography issues. It was found that recently thinned forest is more likely to be damaged than unmanaged dense forest stand. Openness seems to increase the possibilities for damage especially in windstorm. Snowstorm damages forest also in the middle of the stand. Snow loading accompanied by moderate winds on slightly tapering Scots pines caused worst damage.

Introduction

Forest damage caused by wind and snow is a serious economical problem concerning forestry in Europe. The timber damaged by storm is difficult to harvest especially during winter months and is typically low value timber. In addition, fallen and broken trees destroy power lines causing shortages in electricity supply, which may have very severe consequences in remote agricultural areas.

Two severe deep depression storms affected most of the Finland in November 2001. A heavy snowstorm Pyry with moderate winds occurred in central and western Finland on October 31 – November 11, 2001. The 10 minutes average wind speeds were 14 - 18 m/s. In South Ostrobothnia, 30 cm of wet and heavy snow fell on November 1. The snow was near freezing temperatures and froze on the tree crowns. The heavy crowns swung in the moderate wind causing the crowns to snap (Fig. 1). The forests were damaged in large area and thousands of houses were without electricity for several days. During the period of November 15 - 16, 2001 there were very strong winds from Oulu region in the north to the Gulf of Finland in the south. This storm, Janika, had average wind speed between 20 – 30 m/s. It caused less severe forest damage, but in much wider area than Pyry. The damage was caused by gusty winds of maximums between 30 – 50 m/s (FMI, 16.3.2003). The wind speed, snowfall, snow depth and badly damaged areas caused by Pyry are shown in Fig. 2.

The storms of November 2001 felled seven million m^3 of timber in the western and southern parts of Finland. It was estimated that in permanent plots of Finnish Forest Research Institute


Figure 1. Thinned sparse pine forest during the snow storm Pyry
(Photo: P. Pellikka, November 1, 2001).

(FFRI) within the storm region, 1.4% of the total tree volume was damaged. 62% of the damaged trees were Norway spruce (*Picea abies*), 34% Scots pine (*Pinus sylvestris*) and 4% birch (*Betula*). The economic compensation from the insurance companies to forest owners was 15 million e in 2001, while the average yearly compensation between 1990 and 2001 had been 1.8 million euros (FSY 2002).

Both Pyry and Janika occurred in Jalasjärvi municipality in Southern Ostrobothnia. Jalasjärvi is characterized by flat terrain, large open fields and managed forestland. The highest precipitation during Pyry in Finland was measured in Jalasjärvi. In this study, the forest damage was studied in a small woodlot of nine hectares in southern Jalasjärvi consisting of managed and unmanaged mixed pine-spruce stands. This natural test laboratory allows the assessment of the impact of two different storm types on managed and unmanaged forest. The first objective of the study is to evaluate what kind of weather conditions caused the damage. The second objective is to compare the damage levels and types between unmanaged and managed stands, and between coniferous tree species. The topographical factors and location of the stands and damaged trees are also taken into account.

Forest damage factors

Forest damage caused by wind and snow depends on several factors: meteorological factors (wind speed and precipitation), topographical factors, forest stand characteristics, tree species and factors related to landscape, especially openness. Nykänen et al. (1997) has reviewed studies concerning snow damages. Snow damage may occur when a certain snow load will develop weight enough to break the tree components. Snow accumulation is the highest during light winds and decreasing temperatures, but strong winds cause additional bending. The size and form of snowflakes are most suitable for accumulating on trees at temperatures between +1 to -3 C. Even moderate winds can cause damage if trees are loaded by snow. Scots pine and Norway spruce have found out to be more susceptible to wind damages in interaction with snow than birches having smaller crowns during leafless periods. Critical combination of snow loading and wind speed increases when stem taper

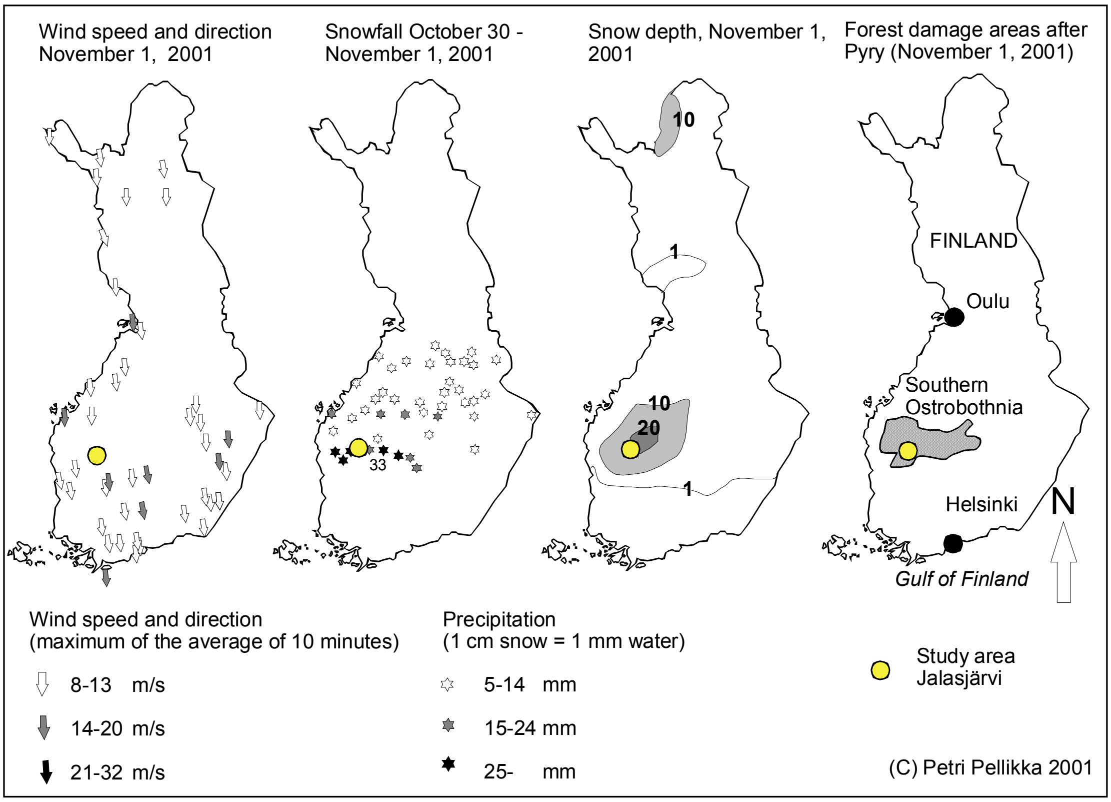

Figure 2. The wind speed and direction, snowfall, snow depth and forest damage areas after Pyry, October 30 – November 1, 2001.

decreases and tree height increases (Peltola et al. 1997). In snow damage, the risk of uprooting increases with tree height, especially when concerning Norway spruce (Päätalo 2000).

Forest stand characteristics and especially management play a significant role. According to Päätalo (2000), unmanaged pine stands are more susceptible to break and uproot by snow and wind than managed stands. The susceptibility of unmanaged stands is caused by low tapering of the trees. However, forest management can also increase susceptibility. Several studies have shown that managed forests are more susceptible. The trees are most vulnerable for snow damage few years after thinning before the crowns have grown wider (Nykänen et al. 1997). It has been also noted that in unmanaged stands trees get support from each others and can stand the impact of snow and wind better (Peltola et al. 1997). Talkkari et al. (2000) noticed, that the damaged stands have usually lower mean stand density than the undamaged ones (Talkkari et al. 2000). Pellikka et al. (2000) studied the effects of freezing rain on unmanaged deciduous forest in Canada and found out that dense and younger stands were able to bear the increased weight on limbs by the ice better than older and sparser stands. It can be concluded that management increases the resistance of the forest, but the few years after thinning are critical. The forest stand can survive if no severe storms appear during the critical years.

Openness and wind direction plays a significant role. Forest stands located near the forest margins or edges of clear-felled areas are more subject to damage due to higher wind speeds (Talkkari et al. 2000). The forests at the edges of fields are more resistant to damage since they are used to strong winds. The most susceptible stands are the newly exposed stands at the edges of clear-felled areas. The impact of wind is the highest on trees when there is a barrier, for example a hill, behind the stand. Talkkari et al. (2000) found out that damaged stands were often located on higher elevations. The timing is also critical. Birches are more susceptible by wind and snow during leafy periods. Heavy winds and snowstorm can introduce bad damage if it takes place before soil is frozen, since the roots are better anchored in frozen soil (Peltola et al. 1999).

Study area

The woodlot studied is part of Tanila farm (4:74 Hannula) located in Koskue village of Jalasjärvi (62°22' N and 22°50' E). The area belongs to middle boreal vegetation zone characterized by coniferous forests. A variety of soil types exist in the area: peat, sand, clay, moraine and bedrock. At the time of the storms, the soil was not yet frozen. The elevation varies between 110 to 125 m a.s.l. The forestland of nine hectares is divided in 11 stands based on forest management and structure. Six stands (2a, 2b, 2c, 4, 10, 11) were managed (thinned or clear-felled) in between 1999 and 2000. Nine stands (1, 2a, 2b, 3, 4, 5, 6, 10, 11) were located at the margins of agricultural fields or clear-felled areas creating openness factor (Table 1).

Data and methods

The meteorological data from FMI (Finnish Meteorological Institute) included synoptic wind observations every three hours of all the Finnish stations for the period of October 30 - November 1, 2001 (Pyry) and November 15 - 16, 2001 (Janika). Daily precipitation and snow depth observations were for October 30 - November 1, 2001. Wind statistics used were from the nearest weather station, at Kauhajoki, located about 35 km northwest from the study area. The precipitation statistics used were from Hirvijärvi station located 15 km northeast. The wind speed in Jalasjärvi region during Pyry was moderate with maximum of 15 m/s and daily precipitation was 30 cm of wet and heavy snow. According to the measurements made by FMI few tens of kilometres south of Jalasjärvi the precipitation fell as water. During Janika the long-term (10 min.) wind speed maximums were 19 m/s in Jalasjärvi region. In the gusts the wind speed maximum was between 30 to 50 m/s. The main wind direction in both storms was north-northwest.

The damaged trees were measured after Pyry. The measured variables were location, diameter at breast height (DBH), falling direction, tree height, species and damage type (uprooted or snapped). The parameters assessed for the stand were species, density, average height, soil, openness, management and area. The measurements were finished just before Janika attacked. The same parameters for the damaged trees were measured after Janika.

Table 1. Characteristics of the forest stands in Tanila farm.

STAND ID	DESCRIPTION
1	Unmanaged pine-dominated sparse and short forest stand on partly open bedrock.
2a	Managed pine-dominated forest on sandy soil. Heavily thinned in 2000.
2b	Managed spruce-pine forest on slope. Slightly thinned in 2000.
2c	Managed spruce-pine forest on wet soil. Thinned in 2000.
3	Unmanaged dense pine forest on peat soil. Drained 30 years ago.
4	Managed sparse pine forest on moraine soil. The area was clear-felled 1952 and the first thinning was conducted in 2000. The stand is located close to field on a small hill.
5	Unmanaged mixed stand (deciduous and coniferous trees) on wet soil.
6	Unmanaged coniferous forest on partly open bedrock.
10	Clear-felled in 1999. Approximately 30 seed trees were left.
11	Old field, which was planted by pines in 1994. In 2001, the trees were app. 2 m high.

A colour infrared (CIR) aerial photograph was acquired over the study area on June 2, 2002 at 10:55 local time by FM-Kartta Oy. The camera used was Leica RC 30 equipped with 153.3 mm focal length lens. No corrections for brightness variations caused by light falloff effect or bi-directional effects (Pellikka 1998, Mikkola & Pellikka 2002) were performed for the photograph since the study area was small. The image was interpreted visually in order to verify the forest stands interpreted in the field in 2001. The photograph was orthorectified by FM-Kartta allowing area estimations for each stands. In early June, the deciduous and coniferous tree species can easily be distinguished in the CIR photograph based on their reflectance differences in the near infrared wavelength area. In CIR photograph, red tone represents deciduous species, while green tone represents coniferous species. Open bedrock appears as cyan tone. The unmanaged and managed forest stands are also distinguishable due to textural differences.

Results

The winds were moderate and precipitation was high during Pyry in large area in Finland, but forest damage was caused only in the area where precipitation fell as snow and froze on trees (Fig. 2). Few tens of kilometres south from Jalasjärvi the precipitation was at the same level than in Jalasjärvi, but it fell as water. The forests south from Jalasjärvi suffered no damage by Pyry, but were damaged by Janika two weeks later.

In the Tanila farm, Pyry damaged 132 mature trees of which 66 were uprooted and 66 snapped. Most of the trees were pines (77%), which is also the most abundant tree species in the area. 16% were spruces and 5% birches. The damage on birch trees was actually higher, but birches, which were bent over were not taken into account in calculation. Janika damaged 34 mature trees of which all were uprooted. Most of the trees were pines (94%) and the rest were spruces. The direction of fallen trees after Pyry and Janika was to the direction of wind flow. It proves that the damage caused by Pyry was not only due to the snow loading. The tree tapering (the relation of DBH to height) of 1:83 for spruces and 1:88 for pines were enough for snow induced damage. The damage caused by Janika for pines required slighter tapering (1:99). The damage on tree species is presented in Tables 2 and 3.

The damage level varied between different forest stands significantly. The density seemed to be very important protective factor in the snowstorm. Pyry damaged mostly thinned stands

Table 2. The damage on tree species caused by snow storm Pyry.

SPECIES	DAMAGE TYPE					AVERAGE DBH (cm)	AVERAGE HEIGHT (m)	AVERAGE TAPER (DBH / height)	AVERAGE DIRECTION (degrees)
	UPROOTED		SNAPPED		TOTAL				
	#	%	#	%	#				
Pine	55	83	48	73	103	20	17.6	0.011 (1:88)	159
Spruce	6	9	15	23	21	19.6	16.3	0.012 (1:83)	151
Birch	4	6	3	4	7	11.4	11.6	0.009	179
Alder	1	1	-	-	1	16	10	0.016	140
Total	66	50	66	50	132	19.3	17.0	0.11	160

Table 3. The damage on tree species caused by wind storm Janika.

SPECIES	DAMAGE TYPE					AVERAGE DBH (cm)	AVERAGE HEIGHT (m)	AVERAGE TAPER (DBH / height)	AVERAGE DIRECTION (degrees)
	UPROOTED		SNAPPED		TOTAL				
	#	%	#	%	#				
Pine	32	100	-	-	32	20.6	19.1	0.010 (1:99)	150
Spruce	2	100	-	-	2	18.5	14	0.013 (1:75)	162
Total	34	100	-	-	34	20.5	18.8	0.011	151

with density around 600 trees per hectare. It damaged between 26 to 40 trees per hectare (Table 4). Pyry damaged trees both in inner parts of the stand and at the edge. The two unmanaged stands on the rocky area (1) and on moist peat soil (3) seem not to have suffered any significant damage by Pyry. Only few trees were uprooted or bent over. Pyry uprooted 5% (40 individuals) of the pines on the old field planted in 1994 (stand 11). The root system of pines planted on old fields, in general, are not typically well developed, and therefore heavy snow caused the pines to fall. Pyry caused also damage on the seed trees on stand 10, which was clear-cut in 1999. About third of the 50 seed bearer pines were snapped or uprooted. Janika caused no damage on this stand since it is located inside the forestland.

Openness increased the damage level at forest margins, especially during Janika. It damaged between 35 to 50 trees per hectare on small stands at the edge of a field (5 and 6). High density of those stands seemed not to prevent damages by the wind. The damage in the unmanaged stand 1 was more severe than damage caused by Pyry. The stands 1, 5, and 6 are located on the southern edge of a large opening introducing openness factor. The soil was also wet and unfrozen in stand 5. Topographic effects were minor since the terrain is flat. Only the damage caused by Janika in stand 4 can be considered to be intensified by gently sloping terrain to the south, which acts like a wind barrier. The damage levels and types are presented in Table 4.

The badly damaged areas can be easily identified in aerial photograph due to sparse canopy and visible forest floor. In Fig. 3, each individual damaged mature tree is marked by a symbol. It can be seen that unmanaged stands 1 and 3 have survived well, except the northern edge of the stand 1. The thinned stands, 2a, 2b, 2c and 4 are badly damaged. The trees especially in stand 4 were still weak. Trees were tall, DBH was small and density was low.

Table 4. Forest stand description in Tanila farm, Jalasjärvi, Finland with damage caused by storms.

Stand ID	Area (ha)	Density (trees/ha)	Stand height (m)	DBH (cm)	Soil	Terrain elevation (m)	Openness	Damaged trees by Pyry		Damaged trees by Janika	
								#	#/ha	#	#/ha
1	2.5	1500	10	17.5	rock, peat	flat, 120 m	N	12	5	10	4
2a	0.8	625	25	27.2	sand	flat, 115 m	N, E	32	40	4	5
2b	0.8	600	23	21.1	rock till	steep slope (W), 110 m	N	16	20	-	-
2c	0.7	714	18	13.7	wet soil	flat, 115 m	E	18	26	-	-
3	1.0	1766	14	11.9	peat	flat, 115 m	N, E, S, W	5	5	-	-
4	1.0	570	16	17.8	sand	gentle sloping (N), 120 m	N, W	32	32	8	8
5	0.2	2080	14	24.7	wet soil	flat, 110 m	N, W	-	-	7	35
6	0.1	1480	10	15.4	rock	steep slope (N and W), 115 m	N, W	-	-	5	50
10	1.7	50	19	19.1	till	flat, 116 m	E, W	17	10	-	-
11	0.7		2	6	peat, silt	flat, 115 m	N	many	-	-	-
Total	9.5							132	14	34	3

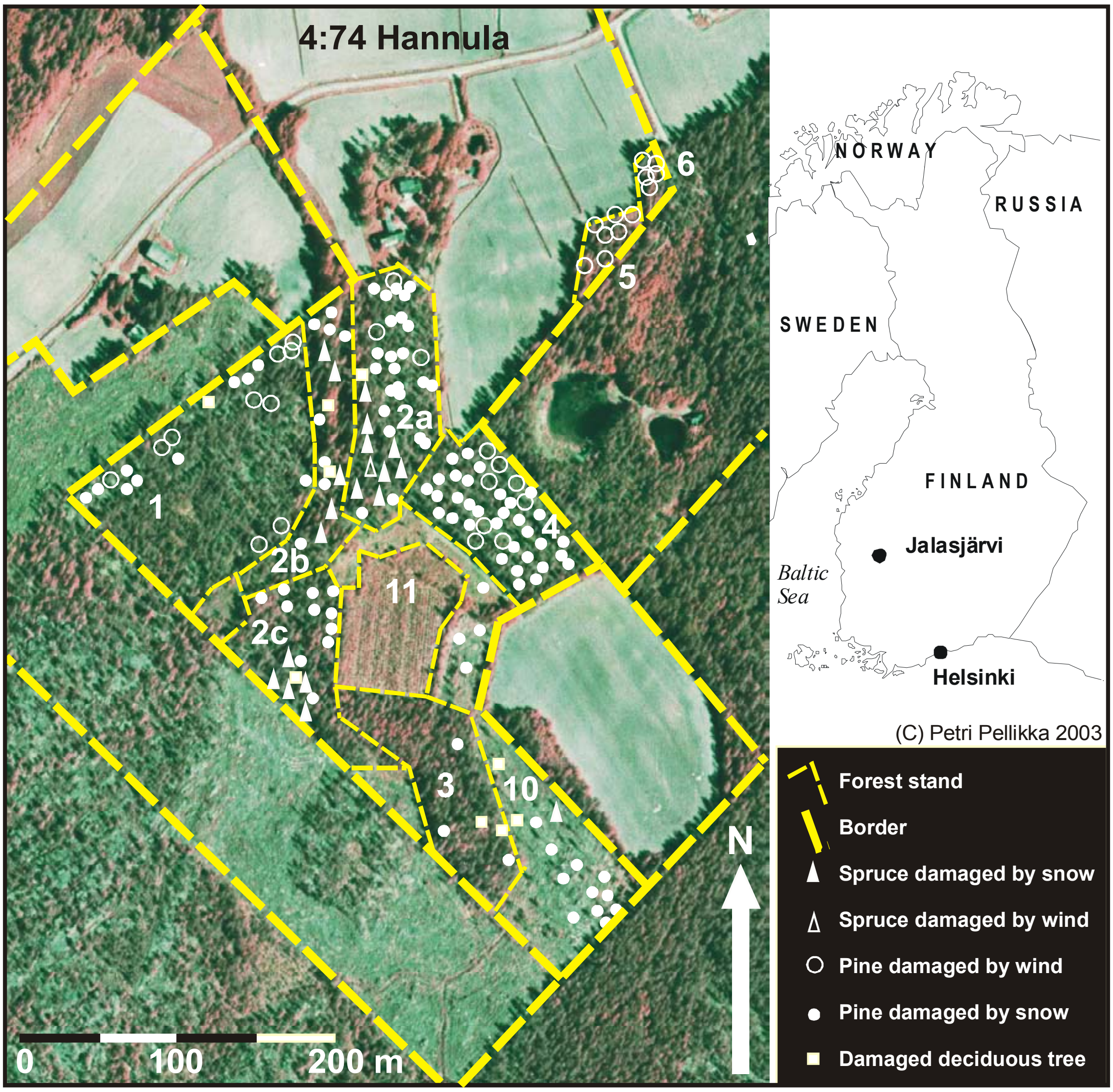

Figure 3. The forest stands and damaged trees by snowstorm Pyry and windstorm Janika on Tanila farm (Hannula 4:74), Jalasjärvi, Finland.

Conclusions

Two reasons for greater damage introduced by Pyry can be found. Firstly, during Pyry, the heavy load of frozen snow on tree crowns was accompanied by moderate winds. According to Peltola et al. (1997), the wind speed of 9 m/s above tree canopy increases the stem breakage risk when covered by snow load. The risk increases with decreasing stem tapering. The low tapering needed for the damage in this case study can be explained by a very heavy snow loading. The frozen snow was not weighted, however, but the wind speed was up to 15 m/s. Secondly, although the factors for the damage vary between snowstorm and windstorm, the weaker trees were evidently pulled down already by Pyry. Damages during Janika took place mostly on forest edges and were caused by strong and gusty winds. The results support the previous studies showing that younger stands are likely to be damaged by snow due to slightly tapering stems (Nykänen at al. 1997). Slightly tapering stems can result also from late thinning. Recently thinned forest stands are more vulnerable to snow and windstorm damages since trees are only slightly tapering and they have more space to swing since their crown is not grown yet and they have no support from neighboring trees. If thinning is delayed until tree height reaches 20 meters, the risk for snow damage is high.

Numerous authors cited by Nykänen et al. 1997, have proved that trees are especially susceptibility to damage after 5 to 10 years after thinning. The worst damage in this case study occurred in stands that were not thinned in 50 years and stand height was about 20 meters. Openness is a notable factor growing the probability for wind damages as observed by Talkkari et al. (2000). The wind energy inside the stand is also higher than at the edge (Peltola 1996). A common remedy to decrease the wind energy inside the stand is to leave the forest edge denser in thinning.

The future work will focus on using remote sensing data to evaluate the forest structure before and after storms. Using forest stand database of additional forestlands in Jalasjärvi, meteorological data, forest company datasets, aerial photography and the results obtained from this study a risk index will be created to different types of forests indicating their vulnerability for snowstorms and windstorms. Such a risk index would be very useful for forestry and electricity companies. The primary goal of the program is to evaluate which structural attributes of the forest and terrain are fragile to severe damages caused by wind and snowstorms.

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