Windfall research and monitoring in the High Tatra Mts., objectives, principles, methods, and current status

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A b s t r a c t: The frequency of heavy windstorms increase in Europe is explained as a possible consequence of the wider global changes. More often, and more intensively, the valuable forest biotopes and protective forest are damaged. Affected sites loose biodiversity, climatic, hydrologic and landscape protection functions, and elevated CO_2 is released into the atmosphere. A windstorm on November 19, 2004 in the High Tatra Mts. downed 12.000 ha comprising the wood volume of 2.3 mil m^3. One of the largest windfall in history of central Europe initiated an extensive international ecological research. Research on climate, soil and hydrological properties, vegetation, fauna and micro organisms is conducted at fixed research sites. Research focuses on temporal and spatial changes of selected indicators. In the summer 2005, three principal research sites were equipped with eddy covariance towers. Sensors for high rate data record (microclimate, CO_2 and water vapour) were installed 5 m above the vegetation. EXT site represents windfall with removed wood and consequent reforestation. NEX site was left without any management; all wood remained on site, and reforestation is not planned. REF site serves as a reference stand. Later, after a large fire which hit 250 ha in the windfall area, FIR site was established. Each site is approximately 100 ha large. Research localities were established at sites with comparable site conditions in the *Lariceto-Piceetum* forest community. Practical application of the research is the rehabilitation and management of the damaged forest for higher ecological resilience in the future. This paper presents principal methodological approaches needed for an extensive cooperative work of more than 20 institutions from 5 countries, and it summarizes the preliminary results.

Key words: windfall, forest ecosystem, ecological research, global change, the High Tatra Mts., eddy covariance

1. Introduction

The forest of the High Tatra Mts. and its foothills were affected by an extraordinarily strong windstorm, reaching the speed of 230 km/h. Consequently, the forest with an area of 12.000 ha and volume of 2.3 mil m^3 was

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downed. The damaged area is located in the Tatra National Park (TANAP) which was established in 1948. The territory of TANAP, besides nature conservation, serves for tourism, recreation, health treatment and research. To fulfil these multi-purpose functions an appropriate natural resource management is needed. From spatial and functional point of view one of the most important natural element is the forest. The forest covers nearly 75% of the national park's territory. The objective of forest management is to keep continuous forest in a functional stage. The forest of Tatra Mts. differs from other mountainous forests in Slovakia mostly due to its unique species composition. The dominance of conifers, mostly Norway Spruce *(Picea abies)*, is natural in this type of forest which shows more similarities with the boreal, rather than European mountainous forests. Natural, and semi-natural forest stands cover more than 50% of the forested land. Forest is a principal habitat for rare and endangered fauna, e.g. wolf *(Canis lupus)*, bear *(Ursus arctos),* lynx *(Lynx lynx*), capercaillie *(Tetrao urogalus)*, etc. Research on forest offers a unique temporal and spatial data on forest development; it also includes a history of natural and anthropogenic disturbances and direct human impact on the forest.

Occurrence of strong winds in the Tatra Mts. is a natural phenomenon. The reason is the geographical location of the mountains, orientation of the main ridge (southwest – northeast) and cross (northwest) direction of prevailing winds. From orographic point of view, the Tatra Mts. form a huge barrier, which causes occurrence of outstanding meteorological situations. One of those is a bora, down-slope wind locally named “Tatra bora” on a lee side, and a foehn, locally called “Halny”, on the northern slopes. Windfalls occur continuously in the Tatra forest. Large windfalls took place in 1915, 1919, 1941, 1964-1968 and in 1981. The result of continuous wind disturbances mostly on the stands of Norway spruce is a high share of pioneer, fast growing, light demanding species, like larch *(Larix decidua)* and pine *(Pinus sylvestris).* According to *Korpel's (1995)* classification of natural forests, this is an example of blocked development between succession and climax stage.

Management of windfall in national park differs from traditional forestry approach used in the ordinary forest. Roughly 10% of the windfall were intently left unmanaged because of conservation of valuable biotopes and also for research purposes. Neither the central European forestry, nor science has yet dealt with such a large and concentrated windfall event. The lack of knowledge and experience was a constraint for the selection and general acceptance of the most appropriate windfall management approach. Consensual decision to apply various management methods initiated extensive international ecological research. In the summer 2005, an agreement on scientific co-operation was signed among Max Planck Institute Jena (D), CEALP Trento, Institute for Biometeorology CNR, Firenze, University Viterbo (I) and Research station of TANAP (SK). Soon, the program named "Windfall research" was officially joined by other institutions, comprising more than 20 organizations from 5 countries.

Frequency of heavy windstorms and economical losses in Europe are increasing. More often, and more intensively, the valuable forest biotopes and protective forest are being damaged. Affected sites loose biodiversity, climatic, hydrologic, and landscape protection functions, and elevated CO_2 is released into the atmosphere. An ambition of this research is also to contribute to detection of the effect of the global change on the forest ecosystems.

2. Objectives of the research and monitoring

Objectives of the multidisciplinary ecological windfall research are:

- to identify both direct and indirect (energy-material flows) changes of a forest ecosystem and its natural elements caused by the 2004 windstorm,
- to quantify temporal and spatial changes of forest ecosystem indicators and parameters,
- to build a monitoring system for long-term observation of damaged forest ecosystem.

The purpose of the windfall research is to gather, analyze and provide information on the territory and its surrounding, the research is used for decision making, management and control activities, especially for rehabilitation of the degraded forest. The main aim of rehabilitation is the improvement of ecological resilience of the future forest.

3. Principles and methods

The assessment of changes on natural environment requires a multidisciplinary approach, team work and a general acceptance of objectives and methods. A key term in a frame of windstorm research is a "status of the forest ecosystem". We understand it as a concept of continuity and discreteness of time and space; it means a status in a certain temporal moment (or interval), or in a selected area, plot and/or point. The status correlates with a process of change (development). It is empirically detectable and measurable by means of some indicators and parameters. The parameters are chosen according to the objective and temporal and spatial scale. We asses the ecosystem status by means of natural elements (atmosphere, water, soil, vegetation, forest, fauna etc.). Based on the importance of individual indicators and parameters for the ecosystem element status, one can reveal the behaviour mechanism of individual elements, and work out a prognosis for future development (*Koreň and Koreň jr., 1995*).

According to the degree of integration, we use two levels of research and monitoring:

a) basic, which focuses on data collection (signs and properties in selected natural elements),

b) integrated, dedicated to the analysis of signs and properties of partial systems. It means "cuts" across natural systems with ties of the same quality and related natural elements.

Temporal agreement is critical for diagnosis and research of changes caused by the windstorm. Besides the natural disturbances, there are other factors causing natural changes with different stability of signs and properties. These kinds of changes are connected to:

– diurnal, seasonal and annual changes of climatic parameters,
– growth and reproduction of organisms,
– natural development (evolution changes).

For identification of spatial changes the following methods are applied: 1) terrestrial and 2) distance. Terrestrial method is spatially discrete, fixed to stable network of research sites, plots and points. Distance method (aerial) provides large scale assessment of selected status indicators. Aerial photography was taken in 2004, 2005, 2006 and 2007 always at the end of a growing season. For both methods, a multiscale approach is applied in order to extrapolate site-wise data across a target area.

According to the degree of representativness, research objectives, equipment and size, there are following categories in a research network:

– research sites, size approximately 100 ha, represent different means of disturbance and different management of windfall, guaranteed frame for undisturbed research and experiments,
– research plots, the areas designated for replication of intensive research, size several hundred m^2 (plant succession, reforestation etc.), up to several hundred hectares – watersheds,
– research points, exact locations for continuous or repeated measurement of physical parameters (air temperature, soil moisture, humus mineralization, soil respiration, nutrient leaching etc.) or fauna occurrence (soil traps). Research points are distributed a) randomly and/or b) systematically (linear transects or regular mesh). The most extensive mesh - forest monitoring network, 500×500 m was established for the assessment outside the research plots.

The criteria for research site selection were as follows: representativness, homogeneity of the site conditions, data from previous research, and accessibility. Forest community *Lariceto-Piceetum* best fitted to the criteria. This community was identified as one of the most vulnerable sites for large scale destruction in late 1990's and was intensively studied *(Fleischer et al., 2005).*

In accordance with the research objectives four study sites were chosen according to the kind of damage (none, windfall and fire) and the consequent management (none or traditional):

1. EXT – extracted site represents traditional way of forestry management. Wood was removed, thin wood and branches were piled and reforestation applied,
2. NEX – non-extracted site represents zero management, all fallen trees were left unmanaged, neither reforestation nor tending is planned in the future,

3. FIR – windfall site party extracted and incidentally burnt,
4. REF – represents intact forest with comparable site conditions, serves as a reference.

Exact location of eddy tower as the priority point in research sites was chosen after several inspections and after 2 months of preliminary measurement of microclimate conditions. The general characteristics of selected sites are given in Table 1.

A special case of a research site is the watershed. Besides fire and insect outbreaks, floods were identified as a prime risk factor after the windfall. Four small watersheds were chosen in co-operation with the NASA project (Fig. 1) to study hydrological responses of disturbed and undisturbed watersheds *(Holko, 2007).* Detailed land-use categories in selected watersheds

Table 1. The general characteristics of the research sites

Research site / Characteristic	REF	EXT	FIR	NEX
Size (ha)	110	95	90	115
Altitudinal span (m a.s.l)	1100-1250	1040-1260	1000-1200	1050-1150
Altitude of meteo tower	1210	1260	1065	1100
Coordinates of Meteo tower (WGS 84, lat, long)	49.121 20.121	49.121 20.164	49.136 20.199	49.160 20.251
Slope %	10-20	10	5-10	5-10
Orientation	SE	S	SE	SE-S
Soil	cambisoil podzolic	cambisoil podzolic	cambisoil podzolic	cambisoil podzolic
Forest community	*Lariceto-Piceetum*	*Lariceto-Piceetum*	*Lariceto-Piceetum*	*Lariceto-Piceetum*
Tree sp share (%) before windfall	Spruce 80 Larch 20	Spruce 90 Larch 10	Spruce 70 Larch 30	Spruce 70 Larch 20 Pine 10
Stand age before windfall	120/25	80	80	125/60/25
Geology-paternal rock	Moraine mindel-riss	moraine donau-mindel	polygenetic debris moraine donau-mindel	moraine wurm

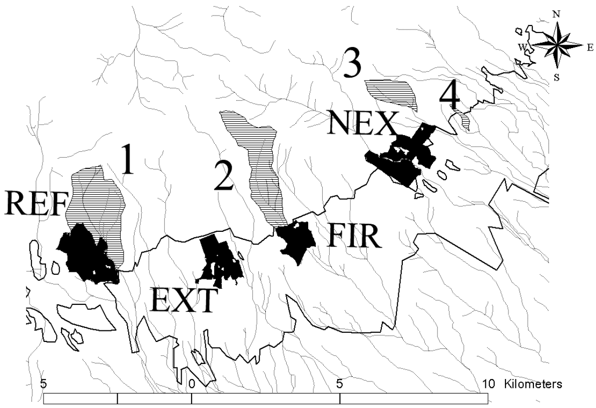

Fig. 1. Location of the research sites (solid polygons), watersheds (stripped polygons) – 1 – Malý Šum, 2 – Slavkovský potok, 3 – Škaredy potok, 4 – Jazierkový potok in a windfall area, (solid line) located on a hydrological map.

are presented in Table 2.

An overview of studied natural elements and status indicators applied in windfall research is presented in Table 3. More indicators were proposed,

Table 2. Land-use in selected watersheds

Watershed Land use	Veľký šum	Slavkovský potok	Škaredý potok	Jazierkový potok
Standing forest	233.18	80.22	37.03	0.62
Fallen forest	10.06	24.93	-	13.96
Krumholz (Pinus mugo)	106.65	85.77	48.61	-
Alpine meadows	12.29	26.34	2.02	-
Rocks	91.12	150.23	24.06	-
Meadows	6.77	1.68	-	
Total	459.07	369.17	114.04	14.58

but only those measured in field during 2005–2008 are listed. Sampling period, sampling frequency and principal methods are listed with each indicator. The model or a manufacturer is noted with electronic devices.

4. Preliminary results

Due to a high variety of studied themes and numerous authors, preliminary results are presented in a limited scope. The source of information is two "Windstorm seminars" organized in 2006 and 2007; presentations were published on a CD (*Fleischer and Matejka, 2007*).

4.1. Climate, meteorology, CO_2

Air temperature since 2004 confirms a trend of increasing both, annual and seasonal values derived from 110 year-long records for the Tatranská Lomnica meteorological station. When compared with a standard (long term average), the most notable changes occur in July 2006, with an average temperature 17.4° C (2.0° C higher than standard). July 2007 was a bit cooler, but the highest maximum air temperature in history was recorded (33.5° C) for station Tatranská Lomnica (830 m a.s.l.). Spring periods in both, 2006 and 2007 were by 2.5° C warmer than a standard. Annual precipitation did not differ from the standard; an exception was April 2007 with only 6 mm of precipitation (standard 50 mm). Drought periods (no rain for minimum 7 days) occurred 5 times in 2006 and 2007. On the windfall site the annual average air temperature was by 1.2° C higher than in a standing forest. Due to an absence of tree canopy the soil receives 50% more precipitation than before; on contrary, the soil is generally much drier. Evapotranspiration conditions changed significantly and lead to reduced amount of available water (*Kňava et al., 2007*). Evaporation increased also due to more windy conditions on windfall sites (*Fleischer and Giorgi, 2007*). Dry and warm growing seasons in 2006 and 2007 caused weakening of spruce forest and favoured mass bark-beetle outbreaks.

Weather in combination with a large amount of flammable material (intently left on sites in various share – 10, 30, 50 and 100% as deadwood) causes continuous risk of fire. In 2007, the high fire risk was announced 12 times.

Carbon dioxide fluxes confirmed that originally intensive soil respiration is being reduced and is compensated by carbon sink in a newly developing successive vegetation. In 2007, carbon balance at EXT site was almost comparable with standing forest at REF site. At the NEX site CO_2 release is a prevailing process due to continuous absence of vegetation cover (*Giorgi et al., 2007*.

4.2. Soil and hydrological conditions

Soil research confirmed relatively uniform conditions on the research plots located at the research sites. General trend is a reduction of organic layer on all disturbed sites. The most evident change is at FIR site. The lack of humus causes significantly reduced water capacity of the soil. The soil moisture increases just after the rain event and drops immediately after that (*Fleischer and Giorgi, 2007*). During a summer season, water volume drops below 15%, in 2007 such a situation did occur 4 times during 30 days. The highest soil moisture was recorded at the NEX site. The reason might be an absence of transpirating vegetation and completely covered forest floor with fallen trunks limiting evaporation.

High air and soil temperature, combined with higher humidity, lead to an intensive mineralization of an organic layer. The consequence is increased flow of ammonia and nitrate towards mineral soil (*Bischoff et al., 2007*) and stream waters (*Fleischer and Giorgi, 2007*). Reaction of soil fauna on ecological changes resulted in 50% reduction of species diversity and abundance (*Čerevková and Renčo, 2007*).

4.3. Vegetation conditions

Change of ecological conditions in former closed forest caused nearly total extinction of original mosses-blue berry-grass vegetation. It was replaced by monotonous vegetation with dynamic changes in abundance. The most spread species become *Callamagrostis villosa* on all disturbed sites and *Chamaenerion angustifolium* mostly of FIR site with elevated nitrogen from mineralized humus. Invasive species *Reynoutria japonica, Lupinus polyphyllus* started to spread into the disturbed areas *(Šoltés et al., 2007).*

Table 3. Natural elements, status indicators, sampling and method

Natural element	Status Indicator	Sampling period and frequency	Method
Climate	Air temperature	Continuous, 30 min avg	HOBO©, Vaisala ©, PT100
	Air humidity	Continuous, 30 min avg	HOBO©, Vaisala ©, PT100
	Wind speed, direction	2005-2008, 20 Hz	Gill Sonic©
		since 2008, 30 min avg	Young ©and Vaisala © devices
	Radiation-G, net, PAR, UV-B	30 min avg	Skye©, Kipp-Zone©, NR lite©, Schultze©
	Microclimate	Continuous, 30 min avg	*Matejka and Hurtalová., 2007, Mišíková et al., 2007*
	Precipitation volume	Continuous	Davis©, Young ©, Vaisala ©
	Precipitation chemistry	Continuous, 2-week sample	ICP Forest
	Air quality – ground level O3	Continuous, 30 min avg	UV detection, Thermoelectron©
Soil	Physical properties	Continuous, yearly	Siewing, sedimentation
	Moisture	Continuous, 30 min avg	Electronic device ML2x©
		Continuous, 2-week ad-hoc	Gravimetric, Aquaterr©, *Hybler and Homolova, 2007*
	Temperature	Continuous, 30 min avg	Electronic device NTC©
	Heat flux	Continuous, 30 min avg	Heat flux plate©
	Chemical properties		
	pH	2x year	1M KCl, H2O extract, *Freibauer et*
	Cox	2x year	*al.,2007*
	Ntot	2x year	*Mičuda et al., 2004*
	C/N	2x year	*Mičuda et al., 2004*
	Exchangeable cations	2005-2008, 2x year	*Friebauer et al.,* 2007, *Mičuda et al.,*
	Trace elements	2005-20082x year	*2004*
	Nutrient content	2005-20082x year	ICP-AES, *Bischoff at al., 2007*
	Nutrient leaching	2005-20082x year	HF extract ICP-AES, *Bischoff et al.,*
	N-mineralization	2005-20082x year	*2007*
	Humus mass loss	2005-20082x year	SIA©, ICP-AES, *Bischoff et al.2007*
	Respiration	2005-2008, campaign	SIA©, *Bischoff et al.2007*
		since 2008, 2-week	KCl extract, *Freibauer et al., 2007*
			Litter bags, *Freibauer et al., 2007*
			Vaisala CarboCap©, *Ziegler, 2007*
			Vaisala CarboCap©
	C and N cycling	2005-2008	*Freibauer et al, 2007*
	CO2 flux	2005-2008	Eddy covariance, LiCOR©, *Giorgi, 2007*
	DOC in soil water	2005-2008	Lysimeters, *Freibauer et al. 2007*
	Erosion	Continuous, 2x year	*Rojan, 2007*
	Microbial biomass	2x year	*Mičuda et al. 2004*
	Diversity	2x year	Biolog© *Gömöryová et al., 2007*
	Activity	2x year	Cellulose test, *Gömöryová, 2007*
Water	Run off	Since 2007, continuous	Gagging station with transducer, Fiedler-Magr©, *Holko and Kostka, 2007*
	Flood hazard	Since 2007	*Holko, 2007*
	Stream chemistry	Continuous, 2-week	ICP, *Bičárová and Fleischer, 2007*
	River morphology	Campaign	GIS, photo comparative

Flora	Species composition	Continuous, 2x year	Fixed plots, *Šoltés et al., 2007a*
	Succession	Continuous, 2x year	*Šoltés, 2007b*
	Biomass	Continuous, 2x year	*Mičuda et al., 2004*
	Invasive species	Continuous, Campaign	*Šoltés et al., 2007*
Forest stands	Health status	Annually 1x 5 year	Aerial photographs, *Fleischer and Matejka, 2007* Network 500x500 m, *Šmelko et al., 2007*
	Biomass	1x 5 year	ICP Forest, *Šmelko et al., 2007*
	Structure	1x 5 year	ICP Forest, *Šmelko et al., 2007*
	Canopy transpiration	Since 2007, 30 min avg	TBH, *Čermák et al., 2004, Kučera et al., 2007*
	Biotic agents	Continuous	*Šmelko et al., 2007*
	Natural regeneration	Annually Annually,	Network 500x500 m, *Šmelko et al. 2007* Transects 2x10m, *Jonášová et al., 2007*
	Reforestation	Annually	Forestry evidence
	Forest history	Continuous	Dendrochronology, *Zielonka et al., 2007*
Fauna			
Soil fauna-Nemathods	Species composition Abundance	Continuous, campaign, transects	Baerman 1917, microscope identification
	Trophic and ecological groups	Continuous, campaign, transects	*Čerevková and Renčo, 2007*
		Continuous, campaign, transects	
Soil fauna-Arthropods	Species composition Abundance	Continuous, campaign, transects	*Čuchta et al., 2007*
		Continuous, campaign, transects	
Insect - flying	Species composition Flying activity	Continuous, 1x week Continuous, 1x week	Malaise traps *Čuchta et al., 2007*
Insect - Carabidae	Species composition Abundance	Continuous, transects monthly	Formalin ground traps *Šustek, 2007*
Bark -beetle	Species composition Abundance	Continuous Fixed sites, 10 days	Pheromone traps Fytofarm© *Majzlan and Ferenčík, 2007*
Micro-mammals	Species composition Abundance Biomass	2x year, fixed transects 2x year, fixed transects 2x year, fixed transects	Harmless traps Capture/recapture, *Hlôška et al., 2007*
Birds	Species composition Abundance Food relations	Continuous, transects Continuous, transects Continuous, transects	Mapping and point method, *Repel and Kropil, 2007*
Parasitic zoocenoses	Prevalence of parasitic agents	Ad-hoc	*Hurníková et al. 2007*

Notable natural forest regeneration started in 2007. The highest seedling frequency shows: Norway spruce *(Picea abies)*, rowan *(Sorbus aucuparia)*, villow *(Salix caprea)*, birch *(Betula carpatica)* and European larch *(Larix decidua)*.

Alarming forest dieback, caused by insect outbreaks, was detected by aerial photographs. The extent of death forest in 2007 was nearly 1000 ha. Higher mortality was detected along the sites with intently left fallen trees.

4.4. Zootic conditions

After the windstorm, fauna at the disturbed areas changed remarkably. Former forest species were altered by generalists; typical for fields, clear-cut, and open meadows (*Šustek, 2007; Repel and Kropil, 2007; Čerevková and Renčo, 2007; Hlôška et al., 2007*). Population density of micro mammals on disturbed sites increased dramatically, prevailing herbivores post a risk for regenerated or planted young forest trees.

5. Conclusion

The 2004 windstorm in the Tatra Mts. caused large economical and ecological damage. However, on the other hand this event initiated an outstanding mobilisation of international research community. During 2005–2008, more than 20 institutions from 5 countries studied the behaviour of forest ecosystems and its elements by using several dozen indicators and hundreds of parameters in a coordinated manner. Most of the research brings something new for disturbance ecology and for the science itself (new insect species?) or for practical management of natural resources affected by the large scale destruction.

Acknowledgments. Author is grateful to all participants who are, or not mentioned in this paper. Special thanks go to Ondrej Jakubjak and Stefano Giorgi for systematic inspection and service of installed instruments.

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