Schedule and Abstracts for Oral and Poster Presenters

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Wind and Trees

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ORAL PRESENTATIONS

The effect of root loss on anchorage of shallowly rooted tropical trees

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Eugenia grandis (Wight) is a shallowly rooted tropical hardwood grown in urban environments throughout Malaysia and root systems are often damaged through trenching for the laying down of paths, roads and canalisation. Therefore, the effect of root cutting resulting from mechanical trenching on the anchorage of mature *E. grandis* grown on sandy clay soil in an urban park was investigated through a series of static winching tests. The force necessary to winch each tree 11° from the vertical (well within the tree's elastic limit) was measured. Trenches were then dug at three different distances (1.5, 1.0 and 0.5 m) from the trunk on the counter-winchward side of three groups of trees, thus severing all lateral roots on one side of the tree. Each tree was then winched sideways again and the force required to uproot or break the tree was recorded. No trenches were made in a control group of trees and these trees were simply winched until failure occurred. Critical bending moment (TM_{crit}) and root relative bending stiffness (RBS) were calculated. Root systems were then extracted and morphology measured.

The effect of trenching on RBS was slight, with a loss of only 13% when roots were cut at a distance of 0.5 m from the tree trunk. Surprisingly, no significant differences in TM_{crit} were observed with regard to trenching distance from the tree stem. When trenching was performed at a distance of 1.5 m from the trunk, a combination of the parameters root system depth and root plate diameter or tree height were the best predictors of both TM_{crit} and RBS and several significant relationships were found between RBS and DBH, tree height and root system width and depth. Therefore, when roots were cut through trenching at distances of less than 1.5 m, something happened to the anchorage mechanism which prevents uprooting resistance being predicted from root system parameters. Thus, it is difficult to give advice to the arborist concerning the minimal distance to be left between the stem and the trench, as this may well differ depending on species, soil conditions and tree vigour. From our study, we suggest a minimal distance of 1.5 m for trees similar in size to *E. grandis* growing in undisturbed soil. The effect of trenching may not be perceived immediately, and there is also a high risk of pathogens entering the severed roots and causing decay in the tree, thus decreasing mechanical stability further. More studies similar to ours need to be carried out on different species in a variety of urban conditions, in order to elucidate further the effect of root loss on trees growing in the built-up environment.

Key words: biomechanics, bending stiffness, critical bending moment, mechanical stability, root architecture

Empirical storm risk modeling with single-tree data from long-term experimental growth and yield-plots in southwestern Germany

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Describing and analyzing empirical storm damage and salvage cuttings on a long-term basis requires reliable data from different time periods. However, such data are scarce: In this respect interpretation of aerial photography or satellite imagery yields good data with reference to large study areas and single incidents, yet information on a stand's development or treatment history is often not available. Long-term records of forest enterprises on salvage cuttings are also a potential data source. These records allow one to estimate general long-term quantities of salvage cuttings and to model stand-level damage probability, i.e. with respect to tree species effects, species mixture, forest edges etc.. In attempt to describe the impact of silvicultural treatment, however, we used a third data source: long-term experimental growth and yield plots which carry detailed quantitative information on the stand's treatment history.

The dataset comprises 1,278 such plots in southwestern Germany, observed between 1889 and 2006, averaging between 0.1 and 0.25 ha in size. They are unsystematically distributed over the state and cover a wide range of site and silvicultural conditions. Measurements of the roughly 360,000 trees on those plots were averagely repeated every five years; however the total observation length varied considerably from plot to plot. Among these are 21,777 windthrown trees, turnover and stem breakage undistinguished.

A wide range of potential predictors were collected that cover different spatial reference levels. On the single-tree level the predictors include tree species, diameter at breast height, tree height, and h/d-ratio. On the stand level several variables describe dendrometric stand properties as well as soil conditions and topographic exposure, and it was possible to include information on stand treatment history as well.

Based on this single-tree data we used generalized linear (mixed) models to estimate storm damage probabilities. Our models give quantitative information on risk factors of storm damage including tree- and plot-level effects on risk predisposition that help in analyzing human impact on risk via silvicultural interventions.

Keywords: long-term risk analysis, empirical wind-throw modeling, silvicultural treatment, multilevel information.

Quantifying wind damage for variable retention harvesting in coastal British Columbia

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The variable retention approach to forest harvesting has been adopted for significant portions of coastal B.C. over the past decade. Varying amounts, types and patterns of stand-level retention occur, ranging from single trees to large patches of forest. A project was initiated on company tenures to document the amount, spatial distribution and pattern of windthrow for retention cutblocks. We also investigated the qualitative and quantitative factors associated with wind damage. The wide geographic distribution of the study facilitated evaluation of regional variation in windthrow.

We sampled 125 harvested blocks over a 6-year period from Southern Vancouver Island (SVI) to the Queen Charlotte Islands (QCI). The 3716 sample plots represent nearly 264 km of external cutblock boundaries, 25 km of large patch edges, 153 ha of small retention patches and 42 km of riparian and other strip edges.

The study showed definite regional differences in wind damage (total % of windthrown trees, broken stems and leaning trees) for those blocks that had experienced at least 1.5 wind seasons. The average damage within 25m of external setting edges was 11% on SVI and 21% on the QCI, with an overall average of 15%. There was a similar regional trend with wind damage for patches and groups. The average damage along the edges of larger patches was 11% for the south coast BC mainland and 45% for QCI with an overall average of 22%. Average wind damage in small groups varied from 14% to 58% across the region. For strips of retained timber, wind damage averaged 31%. Windward edges were more vulnerable to damage than other boundary exposures.

Topographically exposed locations such as ridge crests and upper slopes experienced more windthrow than lower slopes and valley floors. The amount of windthrow also increased with increasing stand height. The distance that windthrow penetrated into a stand edge was affected by some of the same factors as percent windthrow. Penetration along external cutblock edges varied from 6m on SVI to 13m on NVI. Penetration distances were least on lee boundaries and greatest along windward boundaries. A similar relationship was seen with cumulative fetch distance.

Keywords: windthrow, wind damage, variable retention, disturbance ecology

Influence of ecological and silvicultural predisposing factors to windthrowdamage in beech (Fagus sylvatica) stands

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A network of 145 plots measured before 26th December 1999, was re-examined after storm in order to underline and quantify the effect of dendrometrical and environmental parameters on stability of beech (*Fagus sylvatica* L.) high forests in Northeastern France. Furthermore, observed damages were compared with another sample plots : 38 high forest and 40 coppice with standards. These sample plots are located around Nancy, in a very strong wind area (more than 140 km/h) and in similar site conditions. The aim was to identify the morphological tree characteristics and site parameters likely to explain the probability of wind damage.

In high forests, influential factors identified were: wind speed, stand dominant height over a threshold of 23.5 m, depth and type of obstacle for rooting, topography. The influence of all these factors were quantified in a logistic model which predicted the percentage of damaged stems. Nevertheless, no significant effects related to stand density, stand tapering coefficient (*Ho/Dg*), characteristics (intensity and date) of last cut were found. Beeches, especially without leaves, do not react to wind as coniferous trees.

Globally, average damages are similar in both treatments, but, compared to coppice with standards, young high forests are more resistant and old high forests are more damaged. A more precise logistic model was carried out to predict the windthrow probability in very high wind conditions. This single model, valid for both treatments, takes into account : soil depth and tree dimensions (a “lever arm” from ground level to crown middle and crown width). Even if this result seems to be logical, it is different from those found for resinous trees : at given height, the wind damage probability for beeches increases with tree diameter (which is very correlated to crown diameter) and with decreasing tapering coefficient (Htot/DBH). Consequences of these results on beech sylviculture were discussed.

Keywords : storm, windthrow, *Fagus sylvatica*, beech, site conditions, sylviculture, tree shape, dendrometric factors.

The development of turbulence in forest edge flow and its impact on tree motion: a coupled flow-tree simulation study

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Landscape heterogeneities such as forest edges, clearings or gaps modify mean velocity and turbulence fields, in a way that may be detrimental to trees located at the discontinuity or further downstream. In order to predict the flow behaviour at fine temporal resolution in such complex environments, large-eddy simulation (LES) appears as a powerful tool. An LES model based on the ARPS code has been developed for the purpose of providing instantaneous flow fields at fine spatial resolution (2 m) in heterogeneous canopy configurations.

We focus here on the development of turbulence just after the incoming flow has hit the upstream edge of a forest canopy. The simulations provide an average picture of the formation of coherent structures in the adjustment region (from the canopy edge to about 10 canopy heights downstream). This region is characterised by the presence of an enhanced gust zone in the upper canopy layers, where the skewness of streamwise velocity exhibits larger values than further downstream. This feature is the consequence of low-level turbulent kinetic energy being advected upwards from the lower canopy. Further downstream, vertical advection vanishes and shear production leads to the development of a region of large turbulent kinetic energy above the canopy.

Such streamwise variation in turbulence properties has considerable impact on the aerodynamic sollications exerted on the trees. In order to simulate tree motions induced by instantaneous wind forces, we developed a dynamical model of tree behaviour, based on a detailed description of its architecture and mechanical properties. Under the forcing of measured turbulent wind, it predicts swaying amplitudes and temporal patterns in good agreement with those measured in the direction of the dominant wind.

This biomechanical model is finally coupled with the LES code so that the tree response to a fluctuating wind field can be predicted at any location in a virtual canopy. As an example of application, a comparison between a tree at the forest edge and a tree further downstream shows large differences in the distribution of internal strains, both in space and time.

This numerical tool, that was elaborated during the multi-component research project "Venfor", will be used to test the impact of landscape structure on tree load and forest stability.

Keywords: plant biomechanics, forest edge, large-eddy simulation, wind modelling, windthrow risk

Integrating ForestGALES_BC with the TASS/TIPSY growth and yield model

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Wind damages trees in unmanaged and managed stands and both managers and modellers need better tools to predict windthrow losses. Since 2005 we have been working with the BCMOF Decision Support group and the UK Forestry Commission to adapt the UK Forestry Commission's mechanistic windthrow risk model ForestGALES for BC forest conditions and integrate it with the growth and yield model TASS/TIPSY. ForestGALES_BC includes mechanical properties of BC conifers obtained from our recent winching and wind tunnel studies. We have also improved the equations for tree stem and crown representation using values derived from TASS and from our field measurements. The regional/topographic windiness score (DAMS) used in the UK to estimate local probability of a given wind speed and direction have been updated using gridded mean annual wind speed data from numerical weather prediction modelling and local topographic exposure scores. In order to characterize complex cutblock designs and partial cuts, we have developed a spatial interface, WINDFIRM, which characterizes within-opening wind exposure due to fetch and boundary orientation. WINDFIRM assembles and processes data from GIS layers including forest cover attributes, above-canopy wind speed, topographic exposure, for gridpoints at regular intervals across an area, combines this with spatial tree list data produced by TASS, calculates canopy properties and directional fetch and passes the data to ForestGALES_BC. The critical wind speed is calculated for each tree in the tree-list, and this is related to a specified above canopy (reference) wind speed. All trees that would fail at this reference wind speed are deleted from the tree-list. The depleted tree-list is passed back to WINDFIRM. Since loss of neighbouring trees increases wind loading on remaining trees, the tree-list is cycled through WINDFIRM and ForestGALES_BC until the remaining trees are stable enough to survive the incremental exposure. Model predictions will be validated using tree-level results from silviculture systems trials. ForestGALES_BC will be released with TASS version 3.

Keywords: windthrow modelling, spatial design, growth and yield models

Effects of partial canopy removal on windflow: wind tunnel and large eddy simulations.

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Prediction of windthrow risk to retained trees or groups in partially harvested stands requires an improved understanding of airflow and momentum transfer. We used wind tunnel experiments and large eddy simulation (LES) to explore the effects of gap width, retained aggregate size and aggregate-gap size ratios. Formulation of drag without skin friction enabled us to define external length and time scales for the wind tunnel canopy. The non-dimensional formulation of the wind tunnel simulations enables easy scaling to the height of actual forests. The validity of the LES scaling with U0 (ambient wind speed) and h (height of canopy) was tested using 2-D simulations for a discrete block of canopy and we found that the analytical and potential flow model solutions are extremely close during early time periods for the region removed from the narrow shear zone near the canopy-atmosphere boundaries. With 3-D simulations, the statistical profiles for diagnostic wind parameters such as u/u* were similar to those in the wind tunnel experiments. With non-turbulent conditions up-wind, vertical and horizontal flow deflection from the leading row of aggregates sheltered downstream aggregates. Turbulence and turbulence-induced momentum increased for subsequent rows. The number of rows of protected aggregates decreased as aggregate dimensions and the space between aggregates increased.

Keywords: wind tunnel, large eddy simulation, momentum transfer, retention pattern

Impact of forest edge shape on tree stability

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Sharp heterogeneities in forest structure, such as edges, are often responsible for wind damage. This is particularly true when a new edge is created, where trees have not grown in windy conditions. In order to reduce the risks of wind damage it may be of interest to use edge treatment. This study investigates tree vulnerability to wind damage downwind from forest leading edges that have been designed with different treatments: sharp, tapered, graduate, dense, tall and small. To this purpose instantaneous wind and turbulence fields are simulated at very fine scales (2 m) over a range of such forest edges, using the Large-Eddy Simulation (LES) model ARPS. Mean and extreme tree bending moments as well as gust factors are deduced from simulated wind turbulence fields. Downwind from the forest edge they agree with previous wind-tunnel measurements. It is then shown that an increase in the gust factor behind the forest edge region, i.e. from about x = 2h where h is the mean canopy height, is due to the development of coherent eddy structures induced by the tree stand. Unlike wind gusts in the vicinity of the edge they penetrate deep within the canopy through sweep motions. Tree vulnerability is slightly reduced downwind in the presence of tapered and graduate edge treatment, and enhanced downwind by dense edges. Behind tall edges, the gust factor is attenuated in the edge region but it is enhanced further downstream due to the interaction of the canopy with the wake area induced by the edge treatment.

Keywords: forest edge, gust factor, large-eddy simulation, wind modelling, windthrow risk

Large wind throws in managed landscapes -possibilities for conservation of dead wood living organisms

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Southern Sweden was in January 2005 hit by a wind storm that fell 75 million cubic meters of forest. This is equivalent to several years' harvests in the affected areas. The immediate concern was how to take care of the wind throws without to large loss of timber value and how to avoid insect attacks. There were no strategy according biodiversity and conservation in relation to large wind throws, although biodiversity of organisms living on dead threes are recognised as a major concern of forestry and forest policy.

Large wind throws are part of the natural dynamics of forest ecosystems e.g. despite this most of the research efforts have been concentrated to organism responses to wind throws of single tree. The populations of dead wood living organisms are normally substrate limited in a landscape managed for forest timber production, after a major wind throw, suitable habitat should be locally over abundant. Population dynamics are supposed to differ considerably depending on the availability of suitable substrates and the distance between the new substrates and the current populations are important for the colonisation rate. There is thus a potential for conservation of endangered species utilising the population dynamics following a major wind storm.

We identified 500 wind throws ranging from 30 to 7000 cubic meter of timber situated in the whole area affected by the windstorm we have made a first sampling effort on 90 of these windthrows. With a combination of extensive and intensive monitoring will we investigate the spatial and temporal dynamics of populations of dead wood living organisms after a major wind throw. The goal is to give adequate decision support for the policy of natural conservation actions taken after major wind throw events in intensively managed forest landscapes.

Keywords: population dynamics, wind throws, conservation biology, management, landscapes

Assessing tree anchorage mechanisms using a simple 2D finite element model

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Quantifying the role of both root structure components and soil mechanical characteristics on tree root anchorage is still lacking due to the difficulties to design suitable uprooting experiments. Numerical modeling can help to better understand the main mechanisms involved during tree uprooting, as well as the complex interactions between these different factors.

A 2D finite element model of root anchorage has been developed considering:

- two contrasted soil types, i.e. sandy soil and soft clay, characterized using a Mohr-Coulomb model;

- two schematic herringbone like root patterns with different geometries, i.e. with horizontal roots and with lateral roots going deeper in the soil. For each root pattern type, the root elements were removed one by one, including laterals at different depth as well as part of the taproot, and numerical simulations of tree uprooting were performed.

Results have been analyzed with regard to the following criteria: response curves of the root-soil system, including the corresponding stiffness and strength values; position of the root-soil plate rotation axis (or hinge); size and shape of the root-soil plate. In addition, specific analyses of the von Mises stresses at the root surface have been carried out, allowing hypothesis on biomechanical adaptation of root growth to be discussed.

It was found that:

- in soft clay soil, the size of the root-soil plate was determined a priori by few root components only;

- in soft clay soil, oppositely to sandy soil, the position of the hinge was quite stable and only two different response curve paths were obtained depending on the root element that has been removed;

- the taproot contribute significantly to the tree anchorage in sandy soil, when it has almost no effect in clay soil;

- lateral roots going deeper into the ground provided a better anchorage in sandy soil, when horizontal elements were more efficient in clay soil;

- in clay soil, at a distance of the roots attachment, von Mises stresses were greater at the downward surface compared to the upward surface. In sandy soil, opposite distributions were also found.

Keywords: root anchorage, root eccentricity, soil mechanics

Interactions between static and dynamic loading and their influence on acclimative growth in young trees.

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Although many studies on tree growth and their adaptation to mechanical stresses when subjected to wind loading have been carried out, little information is available with regard to how trees react to both a static mechanical stress e.g. growing on a slope and an imposed dynamic perturbation such as wind loading (a situation occurring frequently in mountainous regions). Therefore, an experiment was carried out whereby Black locust (*Robinia pseudoacacia* L.) was grown from seed in pots tilted at 0° and 45° and was also subjected to dynamic mechanical perturbation (MP). Once the seeds had germinated, a bamboo rod was regularly brushed over the tops of half the seedlings. After 23 weeks, shoots were removed and allometry and biomass measured. As root systems often display greater changes in response to MP, we carried out an in-depth study on root architecture and biomechanics. Root systems were excavated *in situ* and root size and 3D architecture measured by hand. Tensile tests were performed on a selection of lateral roots, and cellulose content measured in these roots, as the quantity of cellulose determines root tensile behaviour. The most surprising result was that when growing on slopes and/or with MP, the size of the plant increased significantly. Plants on slopes had shorter taproots with the highest %volume allocated to the stump. The %volume allocated to the zone of rapid taper (ZRT) was significantly greater in the MP treatment only. Root morphology in different sectors around the plant differed in seedlings tilted at 45° only. Without MP, more roots and %volume grew perpendicular to the slope and with MP, %volume of ZRT upslope and deep roots downslope was greater. Tensile tests showed that roots from the MP treatment had a significantly higher resistance in tension compared to those from all other treatments. When slope + MP were combined, roots were significantly more resistant than those from the control and slope treatments. No significant differences in tensile strength were found between roots from control and slope treatments. A significant positive linear relationship existed between root tensile strength and cellulose content. However, no significant differences in cellulose content were found between treatments when root diameter was taken into consideration. Therefore, differences in plant response to dynamic and static loading do occur in young Black locust trees; however, it is not clear what the underlying mechanisms are or how plants perceive different types of loading.

Keywords: mechanical perturbation, architecture, biomechanics, tensile strength, cellulose

Numerical study of the airflow over clearings

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In forest stands, clear-cut areas of different geometry can be found. They are induced by tracks, roads, intersections or they are created by lumbering, forest fires or severe storms. Such clearings represent a discontinuity in the forest canopy causing the atmospheric flow to 'stumble' and to induce mean wind and turbulent perturbations. Thus, clearings can influence the stability of the forest stand. However, there is still a lack of knowledge in order to assess the fluid mechanics involved.

In order to better understand the flow over clearings, a numerical study was performed in which two-dimensional clearings of different width as well as three-dimensional clearings of different shape have been investigated. For the study, a software package based on the standard k- turbulence model was used (FLOVENT/Flomerics Ltd.). The forest stands were simulated by highly porous and homogenous bodies characterized by flow resistances (via pressure loss coefficients).

The results will be presented in isoplots of mean and turbulent flow data and in vector plots. Computed animations will be displayed.

The validation of the numerical data is performed against the wind-tunnel data of ZASCHKE 2006, who modeled a forest as a simple cuboid of highly permeable foam with known pressure loss coefficient.

The results presented in this paper were obtained within the project “Improving the storm stability of forest stands”, which is a part of the "RESTER"-network (strategies for the reduction of storm damage risks for forests) within the research program "challenge: climate change" of the German State of Baden-Württemberg.

Fig.: Flow field over two forest stands separated by a clearing

Keywords: Flow over clearings, k- turbulence model, wind modeling, width of clearing, shape of clearing.

Competition indices as a measure of wind loading on individual trees in a forest stand

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The wind loading a solitary tree has to withstand is a function of the wind profile, crown area and crown drag coefficient. In a forest stand, the relationship is affected by the presence of neighbouring trees which influence the wind profile and increase the damping due to crown clashing. For this reason, a dominant tree has to withstand much higher loads than a suppressed tree which profits from the shelter of its bigger neighbours.

This level of complexity is currently not accounted for in predictions of windthrow risk because wind and trees interactions are modelled at the stand level. As silvicultural practices in the UK move towards the use of continuous cover forestry (CCF), which leads to more irregular stand structures, there is a need to predict wind loading at the individual tree scale. Our hypothesis is that competition indices developed to estimate the amount of light and nutrients available for trees in a stand can also be used to quantify the wind loading on a single tree basis.

A field experiment was carried out in 2005 in a mature Sitka spruce forest managed under CCF in North Wales. The wind profile in the stand was monitored using a 30-m mast mounted with eight anemometers and the bending moment at the base of nine neighbouring trees was measured simultaneously with a high temporal resolution. The nine experimental trees cover a wide range of competitive status.

The aptitude of several indices (Schuetz, Hegyi, etc) to explain the wind loading each tree has to withstand was examined. Results showed that this approach can help predict an important proportion of the variation in wind loading, with several indices giving similar predictions. Improvements in the predictions may be achieved if the competition coming from a neighbour can be weighted as a function of its position in relation to the prevailing wind direction. The advantage of our approach lies in the fact that the output of growth simulators can be used to provide competition indices and hence predict individual tree wind loading as the stand matures. This also allows an assessment of how different thinning strategies may affect the vulnerability of the remaining trees.

Keywords: windthrow risk, wind risk modelling, irregular stands, competition indices

The Future of Wind Damage Modelling

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This paper will review work on modelling wind damage risk in forests with a comparison of empirical and mechanistic approaches and their respective benefits and limitations. The required future direction for wind damage modelling and the most notable deficiencies and weaknesses in current models will be outlined with particular emphasis on ForestGALES . The need to model single tree risk within complex silvicultural systems and complex terrain will be discussed together with the additional requirements this makes of models. Possible approaches to meet this goal will be outlined and the most recent understanding of wind and tree interactions which can aid and inform the modelling process will be presented. The urgent need for detailed data sets to provide rigorous model validation will be emphasised. Finally, the paper will briefly review other wind risk modelling developments and outline a suggested future course of action for the wind damage risk modelling community.

Competition indices as a measure of wind loading on individual trees in a forest stand

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Keywords: windthrow risk, wind risk modelling, irregular stands, competition indices

Dendrochronological reconstruction of wind disturbance events in second-growth Douglas-fir forests

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Disturbance frequency has important implications for forest stand dynamics. In the coastal Douglas-fir forests of the Pacific Northwest, wind is a low to moderate severity disturbance agent that affects stand structure and development. Site chronologies of long-term permanent sample plots were investigated to model the frequency of past wind disturbance events in the Cedar River Municipal Watershed.

Local gap wind events originating from pressure gradients across the Central Cascade Range cause periodic wind disturbance in Douglas-fir forests. These events may cause windthrow, but more often damage individual crowns and cause foliage loss, which has an effect on the diameter growth of the affected tree. Superposed event analysis was used to determine the effect of wind events on tree ring chronologies between 1969 and 1998. Site chronologies showed increasing ring width before wind events and declining ring width during the 2 to 3 years following the disturbance event. This step function was used to detect possible wind disturbance during periods of stand development where no meteorological records of wind events were available. Site chronologies showed an average disturbance return interval of 6.4 years between 1942 and 2003. The relative severity of an event was estimated using the number of sites that registered the wind event.

These results show that local wind regimes can have a sustained effect on tree growth and can be readily analyzed from tree ring chronologies. Knowing which stands will experience more frequent interactions with wind disturbances can guide managers in prioritizing stands for forest restoration treatments or in changing silvicultural systems to reduce windthrow.

Climatology of hurricane winds for the southeastern United States and application to mitigating windthrow risk

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In the southeastern United States, forests are subject to a variety of damage-causing wind phenomena that range in scales from very localized (downbursts and tornados) to broad spatial scales (hurricanes). Incorporating the threat of wind damage into forest management plans requires tools capable of assessing risk across this range of scales. Our conceptual assessment approach involves breaking the risk down into components of event risk and resource vulnerability. Event risk can be simply stated as the probability of an event of a certain magnitude occurring in a given area and can be evaluated based on climatology. Using 100 years of hurricane track information and a simple rankine vortex hurricane model, a climatology of hurricane winds for the southeastern United States is developed to provide information on event risk in the form of probability distributions of wind speed and direction for hurricane induced winds. For wind related threats, resource vulnerability is determined by a complex function of stand and site characteristics. The GALES model is used to assess the potential for hurricane winds to damage managed stands of loblolly and longleaf pine (*Pinus taeda* and *P. palustris*) on a 20 year rotation. Based on the modeling results, recommended management strategies will be discussed that may mitigate the risk of hurricane damage.

Keywords: wind climatology, windthrow risk, wind modeling, disturbance ecology

Aerodynamic modeling of trees for small scale wind tunnel studies

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In the framework of environmental aerodynamic wind tunnel studies, natural vegetative structures like bushes or trees have to be modeled. From a fluid mechanical point of view, these structures differ essentially from man-made constructions (e.g. buildings, cars, planes) because of their structural flexibility and permeability. Whereas the knowledge concerning the small scale modeling of technical structures is wide, less experience on the adequate modeling of vegetative structures is available.

In this article, the aerodynamic characteristics of the flow field of inflexible model trees with permeable crowns are presented. In order to modify the permeability and the aerodynamic behavior, different crown materials and various porosities have been tested. All in all, twelve prototypes were manufactured, six of them with crowns made out of sisal, five with crowns made out of wood wool and one with porous foam crown.

Drag force measurements were performed in a homogeneous approaching flow. The flow field data of the trees subjected to a boundary layer flow were acquired by 2-component laser Doppler velocimetry (LDV). Additionally, pressure loss measurements were carried out for the foam material.

The force measurements resulted in values for the drag coefficient in the range of 0.8 and 1.2, which is in good accordance with observations at natural trees for low wind velocities (< 10 m/s). The velocity data were analyzed in regard to the mean velocity components u and w, as well as to the standard deviations. Furthermore, the friction velocity u_*, the turbulent kinetic energy (TKE) and the velocity spectra of the u component were evaluated. The measurement results show typical wake characteristics of permeable structures with recirculation zones being either extended or detached from the obstacle when compared to impermeable bodies. By means of spectral analysis, an energy shift from lower to higher frequencies, i.e. a break down of eddies, in the crown wake region was found.

Keywords: crown permeability, flow field measurement, drag coefficient, single tree, physical modeling

Ice-storm and forest restoration in Republic of Moldova

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In accordance with data of Agency "Hidrometeo", on 21-25 November 2000 year, air zone with low atmospheric pressure on the South-East of cyclone's periphery, which moved from Great Britain towards Norwegian Sea changed on the end of period air zone with high pressure, which was spread from the East and bond with cold anticyclone. Weather without important precipitations, but with fog and +5+10°C during the night and +6+12 °C during the day was changed on 25 November by the weather with rains (0,0-3 mm during the 12 hours) and fog. The temperature of the air in the frontal zone was in the limits from –1+7 °C during the night and +1+14 °C during the day.

At 26-28 November over territory of Moldova was recorded displacement of height currents that brought to intensification of frontal zone. In the layer near to the ground in the Southwest periphery of the cold anticyclone from the East moved cold air with negative temperatures, but from the West moved warmth and moist air. As a result of this conditions in northern and central districts of Moldova was formed strong ice storm. Its maximum precipitation touched 28-33 mm that brought to the deterioration of line power lines, forests, and orchards. In Moldova were deposited precipitations in the shape of rain, rain with ice; rain with snow, at 27 November was recorded strong precipitations with quantity until 16-44 mm. At 27 November was recorded isolated Eastern and Southeastern wind intensification until 15-24 m/s. The minimum air temperature oscillated in the limits from –2°C until +10°C, and maximum – from –2°C until +11°C.

The ice storm from 26-28 November 2000 has severely affected national forest fund in the districts Orhei, Soroca, Edinet, Lapusna, Ungheni and Balti. The area of affected forests constitutes 51 thousand hectares. Material damages had constituted 135,5 mln.lei (11 mln. $). According to the estimations of economic damages caused to forestry sector constitute: from non-harvesting of high quality wooden mass of exploitable age; from the partial damage of trees and essential reduction of assortment varieties of wooden mass; un-compensated costs for cleaning of damaged areas; from reduction of non-wood forests products of affected forests during 10 years.

As a result of big economical and biodiversity damages both production and scientific institutions are in a dilemma, how to save remaining stand and how to straight the damaged forests into right directions. The problem is how much is necessary to cut or sometimes could be touched this forest not at all? Settlement of this problem separated practitioners and researcher in two groups. First, the bigger one is to cut the most part of forest because to save the wood from disease and pest and after to plant new forest. Second, the smallest one is to maintain the damaged forest for seedling and wildlife protection because of dry climate and then to apply successive cutting in dependence of seedling growing.

Program for Proxy Wind Recovery from Conifers in Baja California

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Preliminary analysis of anisotropy of annual rings in *Pinus jeffreyi* and *P. monophylla* in Baja California show significant relation to PDOI- and SOI-related wind signals, candidates for local downburst events and known and suggested early tropical cyclone landfalls. We will develop both dendroclimatological and biomechanical studies of trees and wind with funding now approved in Mexico.

A biomechanical experiment will record tri-axial deflection of live *Pinus jeffreyi* in response to natural winds and imposed mechanical stress and strain. These properties will then be compared with internal structure and measured eccentricity on multiple transects to gain insight into wind-caused anisotropy.

The dendroclimatological theme will produce a database of multi-species conifer anisotropy at numerous sites between the northern and southern extremes of the peninsula, including Sierra Blanca, Sierra Juárez, Sierra San Pedro Martir, Sierra La Asamblea, Sierra La Laguna and possibly offshore islands. That database will be calibrated using weather station wind records and reanalysis wind and atmospheric pressure time-series data and searched to identify pre-recordkeeping wind events of interest: e.g. tropical cyclones, Santa Ana events, and local anomalies. In the process it is anticipated that further insights will be gained into changing influence of hemispheric scale decadal and interdecadal drivers of wind and precipitation affecting Baja California.

Keywords: proxy wind, wind-caused anisotropy, dendroclimate, PDO, SOI

Fluid Dynamics of Trees

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The purpose of this study is to investigate flow structure of trees as a basic research of windbreak forests and roadside trees. From the viewpoint of fluid dynamics, the measurement of flow velocity distribution behind living trees was carried out by the wind tunnel experiment. We used small size conifers and broadleaf trees as test pieces. A example of the size of conifer is the height of 170mm and the maximum crown width d_0 of 57mm. Flow velocity U distribution behind tree was measurement by a hot-wire measurement technique with an I-type and split film type probe. The split film probe was used for detecting a reverse flow. Main flow velocity U_∞ is in the range of 5~15 m/s which is almost the same velocity as a natural calm wind. The Reynolds number based on U_∞ and the maximum crown width of a living tree d is in the range from 18,000 to 56,000. Figure 1 shows an example of velocity distribution behind a conifer. It was well known that velocity profile behind normal circular cylinder which is typical two-dimensional body shows symmetric distribution. However the velocity profile behind conifer for horizontal y-direction is asymmetric with respect to the wake centerline. This is because the growth conditions of the tree, such as the length of branch and the density of leaves are also the asymmetric. For the tree's height z-direction, velocity profile shows a complicated three-dimensional structure. Vortex shedding from the conifer occurs in the same manner as a normal cylinder. Velocity defect at the position of tree's top and root is larger than that of the potion of the maximum crown width. It was found the reverse flow region exists further downstream than the case of a normal cylinder. Since flow passed through tree's crown which has the porosity of branches and leaves, rollup of shedding vortices were also delayed consequently. In our experimental condition, there was no significant difference of velocity profile between a conifer and a broadleaf tree. It was found that flow structure around tree were almost same as that of a porous body, such as a wire net.

Keywords: Fluid Dynamics, Living Trees, Wake, Drag, Flow Velocity

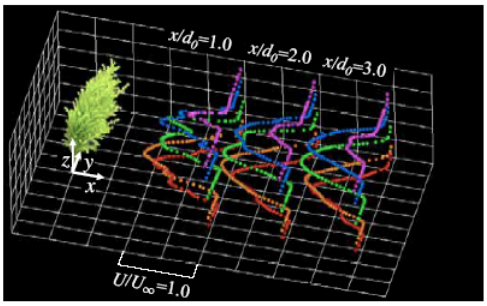

Fig.1 Velocity distribution behind a conifer ($U\infty$=10m/s)

Developing a decision-support system for wind risk modelling as a part of forest management in Japan

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Typhoon wind damage has become a critical issue in Japanese forestry. One significant reason is that planted trees have reached a semi-mature or mature stage without receiving suitable harvesting and thinning. However, wind risk management has not been well developed in Japan. Therefore, this study aimed to develop a decision-support system for risk assessment based on the British empirical-mechanistic model, Geographical Analysis of the Losses and Effects of Storms (GALES), and with a special focus on typhoon wind damage.

This study involved three stages. First, the GALES model was adapted to sugi (*Cryptomeria japonica* (L.f.) D.Don) by conducting tree-pulling experiments to obtain the parameters required for the adaptation of GALES for sugi stands. Second, validation and sensitivity analysis were carried out for the modified version of GALES. By linking GALES and an airflow model (WAsP) estimated damage was compared to actual typhoon wind damage in Himi, Toyama prefecture, Japan. Third, a decision-support system was constructed consisting of GALES, WAsP, a growth model, decision-trees analysis, GIS, and labour efficiency calculations.

The validation of GALES showed more than 70% accuracy in estimating wind damage risk in Himi, although some local adjustment of the wind climate was required. The decision-support system for the Himi region clearly indicated several stands that were at high risk over the simulation period and require immediate intervention. Furthermore, management alternatives can be considered based on tree top height, since top height was the most significant factor related to wind damage in the decision-tree results. The decision-support system provided not only the probability of damage but also management alternatives including significant stand factors, locations, and timing for silvicultural actions in order to minimise wind damage risk.

Keywords: decision-support system, wind damage risk, GALES, decision-trees analysis, GIS

An inventory-based approach for modeling single tree storm damage - experiences with the winter storm 1999 in southwestern Germany

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Based on data on single tree damage caused by the gale *Lothar* (winter 1999) in southwestern Germany (Baden-Wuerttemberg), a statistical model was developed, allowing to estimate the hazard of individual trees being damaged by winter storms. The database consisted of single tree as well as site variables used as predictors, and included a binary response variable attributing whether a tree had been damaged by the storm or not. The data were compiled from the Baden-Wuerttemberg plots of the Second German National Forest Inventory (2001/2002), and comprised tree-level data on 6664 windthrown trees and 57162 trees surviving the storm: in the field, differential diagnosis had been attempted to assess whether trees which had disappeared from the inventory plots had been subject to damage by *Lothar* or not.

In principle, the developed model attempts to separate the impact of tree specific variables (species, height, slenderness), site (distance to upwind forest edge, terrain), and flow field-related effects on the individual trees' risk of damage. Terrain situation was characterized using an extended version of Scott & Mitchell's "*Topex-to-Distance-Index*" integrating an interaction between exposition and exposure. This interaction considerably improved the model's prediction quality and rendered the model sensitive to wind direction as well. The modeled effects of the tree- and terrain specific predictors on the trees' vulnerability to storm damage generally proved in keeping with pertaining expert knowledge.

The problem of missing information on detailed properties of *Lothar's* flow field was solved by fitting simultaneously the linear predictor and a spatial trend function. The spatial trend was fitted using a two-dimensional smoothing spline in the form of a "*penalized regression spline*" to overcome numerical problems occurring under standard smoothing splines. Assuming that the modeled spatial trend expresses the effect of the spatially varying properties of *Lothar's* flow field, the geographical location was used as a surrogate predictor for wind properties. Thus, substituting in scenario studies the real coordinates of a particular locality by the coordinates of another locality chosen from within the flow field allows to transfer the associated wind properties without their explicit quantification.

Keywords: inventory-derived storm damage database, generalized additive regression, penalized regression spline, Topex exposure index, tree-specific effect, terrain specific effect, flow field property surrogate predictor

Degrees of uniform exploitation of stem bending capacity for Norway spruce, depending on site and season

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In order to elucidate the spatiotemporal adaptation of the tree stem growth to mechanical stress, we investigated 13 Norway spruce trees of different age and thinning regimes, growing at high and low elevation sites in Switzerland. Using near-natural tree and load data from previous field and laboratory work, each tree was modeled in non-linear analysis in different seasonal conditions and subjected to complex loading due to wind, snow, debris, and the leaning tree. The analysis of tree reactions included some 3,000 separate model runs grouped in ten combinations of load and seasonal tree state.

The analyses evidence that stem growth is strongly influenced by mechanical stress, both on the material and geometric level. The radial and apical stem growths were found to be best adapted to the most frequent combination of load and seasonal tree state. As a consequence, adaptive stem growth was different on the low-elevation as compared to the high-elevation site, and also depended on tree size, crown characteristics, and stand density.

In the present contribution, we demonstrate the model approach we used, the definition of "degree of uniform exploitation of stem bending capacity", and the most relevant results. Based on our data, it appears that the apparent mechanical optimization of the stem structure plays a crucial role in tree stability and that strong thinning lowers the degree of uniform exploitation of stem bending capacity.

Keywords: anchorage, critical wind speed, failure criteria, flexibility, frost depth, material- and geometric non-linearity, snow load, stem taper

Development and Long-Term Evaluation of Silviculture Systems to Reduce Windthrow Risk in Aspen-White Spruce Stands in Alberta

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The Hotchkiss River Mixedwood Timber Harvesting Study is a cooperative project involving the Canadian Forest Service, Daishowa-Marubeni International Ltd., Manning Diversified Forest Products Ltd., the Forest Engineering Research Institute of Canada and Alberta Sustainable Resource Development aimed at developing new approaches to harvesting systems for western Canada's boreal mixedwoods forests, at a site in northwestern Alberta. The study used conventional harvesting equipment to test eleven harvesting and silvicultural systems over a 530ha site. These include one and two-pass modified uniform shelterwoods, two and tree pass strip shelterwoods, two pass alternate strip shelterwoods, and four pass progress strip shelterwoods. These were used to test varying levels of wind protection designed to protect and minimize wind damage to understorey (immature) white spruce residuals following harvest of the aspen overstory.

A windthrow risk model, developed by the University of Alberta on site, showed strong correlation with observed windthrow dynamics. Ongoing monitoring of wind dynamics and associated windthrow patterns and intensity since project establishment in 1992 have provided clear management practice guidelines for reducing windthrow of immature spruce and residual aspen following harvesting in these stand types. There are clear thresholds related to spruce height and distance from aspen residuals, beyond which windthrow damage increases significantly. The influence of topography, timing of harvest, and the spatial configurations of multiple harvests on windthrow dynamics has been clarified through this research. Results from the Hotchkiss site have been corroborated with windthrow data collected at other white spruce understory protection sites in east-central Alberta. Together with the Hotchkiss results, they have provided valuable information to help forest planners to utilize harvesting and silvicultural systems that best reduce windthrow damage to understory spruce, following harvest of overstory aspen.

Keywords: windthrow risk, wind modeling, white spruce, aspen, silvicultural systems

Drag coefficients, streamlining and crown morphology in flagged Douglas-fir

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Trees are morphologically plastic, and when growing in environments with chronic wind-loading often have deformed crowns and stems. Examining the nature of these deformations provides insights into tree self-design principles and mechanical stability. A total of twelve Douglas-fir saplings were collected from locations with low, moderate and high topographic exposure on highway cutbanks within the Fraser Canyon, near Lytton BC. In this location where the Fraser River cuts through the Coast Mountain Range, differential air temperatures produce daily summer inflows with speeds up to 22 m/s, and periodic winter outflows of similar speeds.

After measuring crown morphology, each sample tree was placed in a wind tunnel at speeds incrementing from 0 to 20 m/s. Wind speed-specific drag and frontal area were recorded. Wind tunnel runs were repeated with the trees rotated 0º, 90º, 180º and 270º relative to prevailing summer wind direction at the collection site. Compared to trees from sheltered locations, trees from the moderately and highly exposed sites had strongly asymmetric crowns and higher crown densities. Crown deformation resulted from branch displacement, not from loss of buds or breakage. All branches from the crown of a symmetric tree were removed from one-side. This tree was tested at different rotations in the wind tunnel to explore the effect of branch alignment. The streamlining and drag behaviour were comparable to the flagged trees, indicating the importance of branch position in development of drag.

Keywords morphological plasticity, thigmomorphogenesis, drag, streamlining,

Wind Effects on Juvenile Radiata Pine Trees Growing in New Zealand

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Toppling, or the windthrow, of young (< 2-3 years of age) trees is a problem in some regions of the world including New Zealand. In this country, the incidence of toppling of young radiata pine (*Pinus radiata* D. Don) trees, particularly on fertile ex-farm sites, has been a concern to foresters. Toppling differs from wind damage in more mature forests in that trees are not blown completely over, but instead attain a lean; a tree is said to have toppled when this lean exceeds 15 from vertical. In many cases trees will naturally correct this lean, although more severe cases require corrective actions such as staking of trees. Impacts of toppling include a higher incidence of stems with basal sweep and reduced selection ratios at time of thinning, which in turn reduces the possibility of achieving the desired final stocking levels. When trees from stands which toppled are harvested this basal sweep is expected to result in increased levels of compression wood.

This paper discusses the phenomenon of toppling and presents an overview of research that has been carried out to identify key factors which contribute to the risk of this occurring and to evaluate treatments which could reduce this risk. Early research efforts focussed on case studies of stands where toppling occurred, as well as field trials to evaluate a variety of crown reduction treatments. A number of detailed root architecture studies have also been undertaken. More recent research has focussed on understanding the biomechanics of toppling. A series of tree winching studies have been conducted to quantify root anchorage strength. Results have been used to estimate the wind speed required to deflect a tree to a certain angle. The effects of dynamic loading appear to be important in tree toppling as tree sway contributes to the progressive deformation of the soil around the root collar – a process often referred to as "socketing". Results from a series of swaying trials to gather information on the natural frequencies and damping ratios of young trees showed that damping of tree oscillations could be enhanced by reducing the length of the branches in the upper half of the crown. This type of crown reduction treatment may reduce the risk of toppling as it not only reduces the wind loading on the crown, but also allows the tree to dissipate energy absorbed from the wind more rapidly.

Keywords: wind damage, toppling, tree sway, compression wood, sinuosity

Windthrow: a geotechnical engineer's perspective

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Resistance to windthrow is a complex interaction between topography, climate, soil type and state, location of water table and the biomechanics of the tree and its root system. Other factors such as silvicultural practice are also important, controlling the height and shape of the tree, and its proximity to other trees. Effective root anchorage is paramount for trees to withstand wind forces and this is a function of root morphology, wind direction, tensile and shear strength of the roots and soil, and the frictional properties of the root-soil interface. Current state-of-the-art in the prediction of windthrow is synthesized into software such as 'ForestGALES', which is used as a decision support tool for forestry management. Whilst databases of tree damage for different scenarios exist, the major producibles from these studies are currently limited to empirical relationships linking wind speeds to basal tree bending moments. Rigorous examination of the biomechanics of the *soil-root-tree* system is still developing and accurate predictions of windthrow events are limited in part due to a lack of a clear understanding of the response of the soil-root system to transferred loads from the tree structure under wind loads.

A recently formed cross-disciplinary team from the Universities of Western Ontario and British Columbia, in concert with Environment Canada is conducting post-storm damage surveys in Ontario. Part of this work involves estimating boundary layer wind speeds from field tree damage and windthrow cases. These studies will eventually include small scale physical modelling in soil boxes and wind tunnel tests, coupled with finite element computational methods. There are obvious parallels between the biomechanical performance of tree root systems and the attempts by geotechnical engineers to create efficient supporting foundations for laterally loaded structures. This paper will discuss the interpretation of the pre and post failure behaviour of soil-root systems from the perspective of geotechnical engineering. Items of interest will include soil-root interface properties, complex multi-axial foundation loading, rates of loading and cyclic load degradation of soil stiffness, foundation failure modes, root growth and 'initial' soil states, and mini-pile group spacing and raking angles. Windthrow data and preliminary analysis from the recent F1 tornado in Bornholm, Ontario will also be presented.

Keywords: windthrow, pile behaviour, soil mechanics, foundations, soil-root interaction

Improvements in anchorage provided by the acclimation of forest trees to wind stress

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Trees have long been known to modify their above- and below-ground growth in windy climates. This acclimative growth is believed to reduce the risk to the tree of damage or death during wind storms. However, although secondary growth rates have been altered in experiments by manipulating the mechanical stress experienced by trees, the adaptive growth response to wind stress has not previously been linked directly to an alteration in anchorage strength of forest trees.

In this study we reanalyzed a data-set of tree-pulling experiments to examine the relationship between wind exposure (DAMS Score) and the development of root anchorage (critical turning moment). Data were available from almost 1000 Sitka spruce trees that had been mechanically overturned on 25 sites in the UK. These data were separated between soil groups (free-draining mineral, gleyed mineral, peaty mineral and peat soils), and shallow (<40 cm), medium (40 – 80 cm), and deep (>80 cm) rooting depths. Regressions of critical turning moment against stem mass were performed on each combination of soil group and rooting depth, with DAMS as an additional explanatory variable.

DAMS had a significant positive effect on the slope of the critical turning moment against stem mass regressions for Sitka spruce on some, but not all, soil groups and rooting depths. This wind exposure effect on anchorage was found for trees on poorly drained mineral soils (gleyed mineral and peaty mineral soil groups) with shallow and medium rooting depths (<40 and 40-80 cm). The implications of trees developing stronger root anchorage in locations with greater exposure to wind, is discussed in relation to modelling and managing wind risk to forests.

Keywords: mechanical stress, wind, acclimative growth, anchorage, windthrow risk

Turbulent Flows in Forest and Clearing Configurations: Wind Tunnel and Flow Simulation

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Silvicultural practices in British Columbia are changing rapidly in response to environmental and other pressures. The new practices result in a number of different forest/clearing configurations superimposed on already complex terrain. Systematic study of the effects of these many configurations on wind speed and turbulence, the major driving factors for windthrow that also affect the microclimate in both clearings and the forest, in the field is difficult, expensive, and time consuming. Wind tunnel measurements and numerical flow simulation offer cost-effective alternatives to field studies. The Biometeorology/Soil Physics group at UBC has used the large Mechanical Engineering tunnel for this purpose and collected an extensive set of data. This presentation will report some of these results and compare them with field measurements, which are available for some specific cases, and computational fluid dynamics simulations based on k-ε type models of turbulent flow.

Keywords: windthrow risk, microclimate, wind speed, turbulence, wind tunnel, computational fluid dynamics

Risk management of wind damage in forest planning based on heuristic optimization

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In this paper, we will introduce into the field of forest planning the risk management of wind induced damage as a spatial objective or constraining variable in order to find out how the risk considerations may affect the temporal and spatial pattern of management actions (e.g. clear cuts) within a forest unit, and as a consequence the expected net incomes over certain forest planning periods. This will be done by employing different heuristic techniques (such as simulated annealing, tabu search and genetic algorithms) together with a forest growth model (SIMA), mechanistic wind damage model (HWIND) and GIS software (ArcGIS).

We will demonstrate in this paper that within the forest unit the risk of wind induced damage could be decreased e.g. by aggregating clear-cuts and by avoiding them especially at the edge of stands with a high risk of being damaged (e.g. older Norway spruce stands). On the other hand, even-flow timber harvesting objective may limit the possibilities of minimizing the risk of wind damage. We will also demonstrate that the optimization results are quite sensitive to the criterion of critical wind speed that will be used to classify the stands into those ones having risk and those having no risk, which should be kept in mind when aiming at to generalize the findings of this work.

Keywords: Wind, risk management, forest planning, growth and yield modelling, mechanistic modelling for wind damage, heurestics, integrated model approach, GIS.

Assessment of Wind Vulnerability in Two Maine Landscapes

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Numerous factors, some of which cannot be controlled, are continually interacting with the forest resource, introducing risk to management, and making consistent predictable management outcomes uncertain (Birot and Gollier, 2001; Wilson and Baker, 2001) Included in these factors are threats or hazards such as windstorms and wildfire. This project will detail an approach developed to assess wind damage risk across two forested landscape in northern Maine.

Factors influencing the probability (risk) of windthrow or windsnap occurring can be grouped into four broad categories: regional climate, topographic exposure, soil properties and stand characteristics (Mitchell, 1995). Of the three categories, stand characteristics are most commonly and easily modified through forest management.

Vulnerability to wind damage in Maine may increase in the future because of three trends currently influencing stand conditions. One, Maine forests contain a considerable amount of balsam fir and red spruce, tree species that are considered particularly susceptible to wind damage. Two, extensive areas regenerated after the 1970s and 1980s era spruce budworm outbreak are maturing. Three, partial removals currently account for over 74 percent of the area harvested annually in the state (McWilliams et al. 2005).

The model was tested on two separate tracts of land. The first is a managed landscape encompassing a 40,800 hectare forest area in northern Maine with spatially explicit wind damage records. The second area used in model evaluation is a 2,023 hectare preserve in the same region of the state with no known history of timber harvests. Tests identified significant differences in vulnerability index values between categorical populations of stands that have either recorded blowdown or no blowdown during the last fifteen years.

To avoid problems with spatial autocorrelation ten random samples were drawn from the study area and evaluated individually with a Mann-Whitney non-parametric comparison of means test. Results from the ten samples were pooled, and compared with a one sample comparison of means t-test (alpha 0.05) to test for consistancy.

Keywords: windthrow risk, wind modeling, natural disturbance

Salvaging changes microsite abundances after deciduous forest windthrow

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Forest disturbances create microsites, such as downed tree crowns and boles, stumps, and treefall pits and mounds, which differ in conditions and resource availability, diversifying establishment conditions for a variety of species. Salvage logging after wind disturbance may alter the abundance of wind-created microsites and thereby alter regeneration opportunities for species that germinate preferentially in these microsites. In a wind-damaged forest in western Tennessee, USA, we documented microsite abundance in salvaged and unsalvaged portions of a wind-damaged forest and determined whether environmental conditions and vegetation characteristics varied among microsite types and/or treatment (salvaged or not). The wind disturbance at our study sites (with or without salvaging) increased diversity of the seedling layer by allowing germination and survival of shade intolerant species within disturbance-created microsites. As predicted, microsite abundances differed between treatements. Contrary to our expectations, we found no evidence that pits and mounds were destroyed by salvaging operations. While understory abundance and species richness differed among microsite types, they did not differ between salvaged and unsalvaged treatments. Similar to other studies, soil temperatures were highest on mounds while soil moisture was highest in pits than among other microsite types. Additionally, salvaged areas had warmer soils and greater canopy openness. Overall, microsite type was far more important than treatment in influencing vegetation parameters. However, salvaging operations were of very low intensity at NTSF and this generalization may not hold following higher severity disturbance and/or higher intensity logging operations.

Keywords: windthrow, regeneration, salvage logging, microsites, pits, mounds

CFD modelling of airflow through a forest stand and clearing

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Airflow was modelled using FLUENT, a computational fluid dynamic (CFD) program. FLUENT modelling was validated using wind tunnel measurements made at the University of British Columbia from an earlier study. A flow domain, similar to the UBC wind tunnel, was produced for FLUENT, complete with bluff bodies, large and small roughness elements. Two stands were produced separated by a clearing approximately 11 tree heights long.

The 6-, turbulence model, along with two variations was used to parameterize turbulence. The two variations were the realizable 6-, and the Renormalized Group (RNG) 6-, turbulence models. Steady state simulations were performed as well as unsteady simulations. Unsteady simulations were run with 2500 Hz timesteps, for at least four seconds.

Forest stands were created three different ways. The first way was using tree shaped entities that were solid - had no porous components. The second method was to create a rectangular shape divided into six porous sections that represented different levels of the canopy. The final examination was to take the tree shaped entities from the first method and assign them a porous characteristic similar to the second method.

Predictions from the models were compared with wind tunnel observations using the root mean square error and the Willmott d statistic. These were calculated from 29 vertical points within and above the stand from ten locations, which included four locations within the stand (two upwind and two downwind of the clearing) and six inside the clearing. The results suggest that FLUENT has skill in replicating wind tunnel measurements of airflow past trees.

Keywords: CFD, kappa epsilon turbulence model, wind modelling, forest stand, forest clearings

A Numerical Analysis of the Effects of Tree Architecture on its Dynamics

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Wind can strongly affect trees, not only in terms of damage during storms but also in term of growth and form [1,2]. A tree is a complex structure organized in a branching pattern from the stem to the tips where most of the foliage is located [3]. While most of the wind excitation is due to the drag mechanism acting on leaves or needles which will then induce the movement of the lower orders of the structure (stem, first order branches), it has also been shown that the foliage is the main source of the whole tree damping [4].

The numerical analysis of two extreme idealized tree architectures is developed here to give some insights in their dynamics. Two-dimensional finite element models of 1.(a) a monopodial and very hierarchical tree inspired from the Rauh model ([3] eg. spruce) and 1.(c) a sympodial tree inspired from the Leeuwenberg model ([3] e.g. cassava) have been developed assuming allometric relationships between branches length and radius and between different branching orders as described in [5]. A damping effect due to the foliage has also been modeled.

The consequences of these architectures on the vibration dynamics are characterized in terms of modal decomposition. Mode shapes (see figure 1.(b,d) for the 1st modes of the two architectures), modal frequencies, masses and damping are calculated. Emphasis is given on the relationship between mode frequencies, modal mass and modal damping found for the two architectures. Comparison is also made with mode frequencies from experimental results reported in literature.

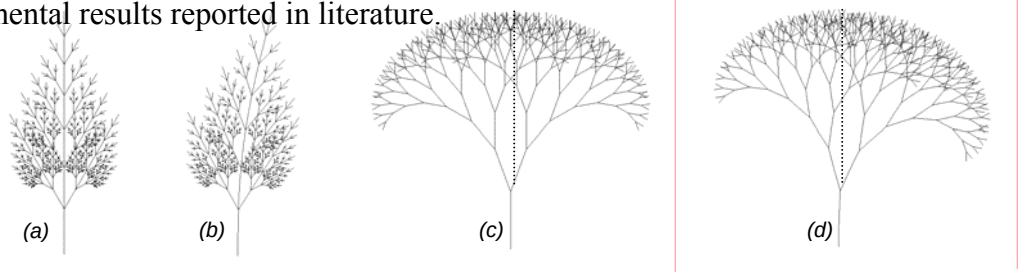

Figure 1. Monopodial architecture (a) and its first mode shape (b).
Sympodial architecture (c) and its first mode shape (d).

Keywords: Biomechanics, tree, dynamics, damping.

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Dynamics of realized sway period in coniferous and deciduous canopies

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The periodic motion of trees is fundamental to understanding their absorption and dissipation of wind energies. While the natural frequency or period of trees is well studied, their realized period, motion subject to wind loading and various damping factors, remains poorly understood. In a closed forest canopy, the loading and damping of trees creates a complex dynamic system whose behavior under different wind conditions and canopy structure is rarely quantified. Biaxial clinometers mounted on the bole at a height of ~9m report bole rotation at a rate of 10hz. Sway displacements were then calculated for 10 lodgepole pine trees at two sites in Alberta, Canada and at one site for 7 red maple trees in Connecticut, USA. Sway periods were derived by applying Fourier transforms to sway displacements. The realized period for all trees was hypothesized to increase with increasing wind speeds as crown collisions are assumed to dissipate proportionally more wind energies. The realized sway periods of red maple trees were hypothesized decrease after leaf off; which would mimic the response of the natural sway period.

Examining realized periods between pine stands indicates trees in the more slender stand have larger sway periods that increase with increasing wind speeds while more stout trees have significantly lower periods that did not change with wind speed. Realized sway periods for all red maple trees were similar regardless of their slenderness and did not appreciable change with wind speed, direction or between leaf on and off. The observed increase in sway period with wind speed for trees in a slender pine stand may be attributable to the large amount of crown shyness present in the canopy. The large space between tree crowns could allow a building of inertial energy increasingly dependent on crown collisions for dissipation. Findings suggest that canopy architecture, has an important role in the dynamics of realized sway period.

Keywords: realized sway period, crown collisions, sway frequency, deciduous, crown shyness

Adapting the ForestGales model for complex stands.

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The ForestGales model is an operational mechanistic model that has attracted a lot of interest since its original distribution. This model was initially designed with a focus on U.K. Sitka spruce plantations. Other species were also considered and studies conducted in many regions provide the basic relationships to expand the model to many single-species, regular stands. However, there is also a need to estimate windthrow risk for multiple-species stands or for stands of complex structure. In order to verify the implications of adapting and using the model for such stand types, we have conducted field experiments to verify the robustness of the relationships and a sensitivity analysis for some of the model parameters. Black spruce, which grows in a wide spectrum of conditions, has been the focus of the study.

Calculation of overturning resistance in the model is based on stem mass, soil type, site preparation and species. Tree pulling studies are used to build these relationships. Soil type affected differently black spruce and jack pine growing together in mixed stands. Black spruce resistance did not differ between the soil types investigated. However, an effect of stand structure was found for sound trees that overturned. Results also suggest an important role of stem decay in irregular, virgin stands. Prediction of crown size required the use of stem weight, spacing and H/DBH ratio. The latter two differed between stand structures so that crown size was larger in irregular stands. Critical wind speeds were computed with ForestGales using the regular approach and the one suggested by Mason (2002) for irregular stands. For the black spruce stands of the winching study, there was a high within-structure variability of critical wind speeds such as the difference between structures was generally not significant. Calculating critical wind speed for the dominant tree instead of the mean tree could have a strong effect. Within the range typical of irregular black spruce stands, spacing does not have a strong influence on critical wind speeds.

Keywords: windthrow risk, mechanistic models, ForestGales, mixed stands, irregular stands

Silvicultural options at the stand level to minimise wind damage

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There is a vast body of literature on the influence of stand management on windthrow susceptibility. Most of this work is based on statistical analysis after observed windthrow events. However, such analyses are usually hampered by many difficulties, such as uncertainty of the exact stand conditions before the storm, no exact figures of wind speed and gustiness, a lack of stands in all desired stages, conditions and site classes. Furthermore, usually only one storm with a certain wind speed is considered, which makes extrapolation to other windspeeds difficult. As a result, recommendations and management guidelines can differ considerably and are sometimes even contradictory between studies.

In recent years, enormous progress has been made in the field of windthrow modelling. One example is the ForGEM-W model, which combines a distance-dependent individual tree growth model with a mechanistic windthrow model. During a simulated strong wind event, damage probability is evaluated individually for all trees. Individual tree characteristics are thereby taken into account, as well as shelter and support from surrounding trees and additional loading by falling trees. This allows the user to compare the effectiveness of different management systems with respect to their susceptibility to windthrow. We tested 13 different management regimes for Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Netherlands over a full rotation. Selected management regimes ranged from traditional yield table management to unevenaged mixed selection systems. All management regimes were subjected to the same weather conditions to ensure maximum comparability. Management regimes are evaluated not only for the occurrence of storm damage, but also in relation to other characteristics like total wood production and dimensions of the produced wood.

Keywords: windthrow risk, wind modelling, forest management, individual tree modelling

Responses of two groups of Scots pine trees to dynamic wind loading

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In a Scots pine (*Pinus sylvestris*) plantation in SW Germany the responses of two groups of ten adjacent trees with different inter-tree spacing to dynamic wind loading were investigated. In two measurement campaigns wind vector components and wind-induced tree displacement were measured at a rate of 10 Hz. Wind vector components were monitored by ultrasonic anemometers which were mounted at a scaffold tower erected close beside the two groups of trees. Each of the ten selected trees was instrumented with three biaxial clinometers to measure tree displacement at different heights. The spectral characteristics of the trees were similar. Results of space-time correlation analysis between shear stress and tree movement reveal similarities in the responses of the Scots pine trees to wind loading. Based on tree movement measurements, crown interactions among the ten trees were analyzed. Crown interaction analyses show that as wind speed increases, the number of crown collisions, crown collision speed, and crown area overlap also increase. Trees were found to act like damped harmonic oscillators. The coupling of the trees was simulated by a spring/damper system.

Keywords: wind loading, tree sways, crown interactions, Scots pine

Wind induced successional changes at different scales in a pristine boreal forest

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The study examines the role of wind in developing structure and dynamics of the Norway spruce (*Picea abies*) dominated pristine European boreal forest "Vepssky Les" at the scales of (1) micro-site, (2) forest stand and (3) landscape. The case study conclusions are based on the records from permanent sample plots (13) established in the 1970s, regularly distributed 0.1 ha permanent circular sample plots (74) established in 1991, transects established in 2000, analysis of the air photo images since 1970, forest inventory data since 1913, thematic mapping in 1978 as well as dendrochronological research.

1. The windfall complexes constituted 6 to 11% of the ground area. 71 species of bryophytes and lichens and 22 species of vascular plants were found on these microsites.

2. The structural and dynamic diversity of forest stands were influenced by frequency and severity of windthrows. The endogenic dynamic pattern was typical for the all-aged forest stands on paludified soils (*Sphagnum-Myrtillus, Sphagnum* ecotypes). The cohort replacing and stand replacing windthrows leading to formation of the even-aged and uneven-aged stands occurred on more productive well-drained sites (*Myrtillus, Oxalis* ecotypes).

3. The average standing volume of the forest landscape increased from 172 to 324 m^3 ha^{-1} in the period of 1913-1983 and then decreased. Strong wind in the 1980s led to blowing down of the most productive stands. Synchronous regeneration of the even-aged stands and cohorts in the uneven-aged stands has been observed. During the period of 1981-1997 on the area of 573.2 ha the number of gaps more than 0.1 ha increased from 8 to 63; total area in gaps increased from 1.52 to 28.8 ha; average gap size increased from 0.19 to 0.46 ha.

The study generalized results acquired by research team from the Saint-Petersburg State Forestry Research Institute and Forest Technical Academy since 1970s. Financial support was provided by government of the Leningrad region, Natural Park "Vepssky Les" and Russian Foundation for Basic Research (05-04-48476-a, 06-04-63039-k, 07-04-00200-a).

Reforestation after windthrow in Ural: Models on Different Scales

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To understand forest development after a windthrow event and to project it for the next decades, we apply different modeling approaches, which work on different temporal scales and spatial resolutions. Modeling is based on data of forest development from Ural covering thirteen years after windthrow as well as the composition of the remaining stand. In the first group (A) of models we describe the pecularities of short term, local forest dynamics. Model A1 is a generalized analytical model of the forest-grass community, where the components (grass, young trees and adult trees) have various characteristic times. It is based on the FitzHugh – Nagumo equation, which describes the competition in the community and the possible regimes of system behavior. Model A2 describes the dynamics of tree numbers on the territory after windthrow, where we take into account the influence of seed flux from neighboring territories, competition with grass, and other young trees. Model A3 is based on the Zipf-Pareto and Mandelbrot equations and describes the competition between young trees of various species. Model A4 is a Markov chain model with Erlangian distribution of state-to-state transition time which describes short-term succession dynamics in forest stands after windthrow. A second approach (B) simulates the spatio-temporal forest dynamics for several centuries. It uses the forest landscape model TreeMig, which has been extended by a wind disturbance module. The data of long-term observations of reforestation processes after windthrow were used for verification of all models. The comparison of model and natural data allow to estimate reforestation dynamics, the changes of competition processes in stand, the peculiarities of the trees' spatial distribution. The models are applied with different scenarios of wind events, wind impacts and climate change and thereby yield a range of potential future forest development in the study region. Furthermore, the combination of the approaches gives insight into the general behaviour of the ecological community and into the processes governing it. Thanks to UralHydroMet, Ekaterinburg, Russia, for the meteorological data. This work is sponsored by grant SCOPES Nr. IB74A0-110950 of the Swiss National Fund

Keywords: reforestation, windthrow, succession, long- and short-term models, landscape model

The integration of airborne LiDAR to ForestGALES to estimate wind loading on individual trees

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Airborne laser scanning (ALS) has been used to extract individual tree parameters to run a wind risk model (ForestGALES) at tree level. Different canopy delineation algorithms have been tried to identify individual trees in the field, extract tree height and canopy dimensions and the spatial distribution of different dominance types, as a way to assess the effect of stand structure on wind risk. Allometric relationships derived from Forestry Commission growth models and the Canadian growth model TASS have been incorporated to estimate parameters not directly observable by the sensor or the segmentation algorithms such as stem diameter, canopy length or the actual extent of the canopies growing underneath neighbouring trees. The results have been input into the ForestGALES model as tree lists in order to determine the sensitivity of the predictions to these parameters. The spatial location of the most vulnerable trees in the forest will increase current understanding of the effect of stand structure (dominance distribution and canopy gaps) on the probability of wind damage. Furthermore, the canopy delineations have been used to evaluate the sheltering effect of neighbouring trees (e.g. damping due to crown clashing) as a ratio between available growing space and occupied space. The use of tree lists allowed more accurate predictions of wind damage than the ones generated with stand information gathered in the field or from the Forestry Commission sub-compartment database. The fact that this information could be obtained in a semi-automated way enhanced the operational capabilities of ALS as a cost-effective alternative to field data collection and increased the operational use of ForestGALES by forest practitioners. A study area was located near Aberfoyle village (56º 10' North, 4º 22' West) inside the Trossachs-Ben Lomond National Park in the west coast of Scotland. ALS data were acquired in September 2002 and June 2006 with a total survey area of 17.5 km^2. Field data were also collected in order to test the accuracy of the canopy segmentation models and the predictions of wind damage. The collection of data in the field consisted of 12 square plots each a quarter of a hectare in size covering Sitka spruce (Picea sitchensis) stands aged 31-33 years old. As this area was severely affected by wind damage in December 2005, the two ALS surveys have been used to validate the predictions of the model, monitoring those parts of the forest affected by windthrow and the response of the vegetation to the newly opened gaps.

Keywords: ALS, LiDAR, windthrow risk, wind risk modelling, irregular stands, competition indices, ForestGALES.

Self-Induced Oscillation of a Standing Tree in Wind

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It has been hypothesized that trees are wind damaged by only wind pressure induced by strong wind. However, anecdotal evidence suggests that vibrations of standing trees are amplified by strong wind, and such amplified vibrations are also considered to influence the destruction of trees. Since standing trees have natural sway frequencies (e.g. Moore and Maguire (2005) Trees19(4): 363-372), they may resonate with strong wind. Therefore, vibration characteristics of standing trees need to be better understood to clarify the mechanisms of tree damages by strong wind.

We carried out a measurement of tree vibrations in a Cryptomeria japonica plantation field and a free vibration analysis of a standing tree. Our objectives are to investigate 1) the value of the natural frequency of a tree and 2) the influence of the natural frequency to the motions of the tree in a field.

Toward these objectives, we developed displacement meters that use potentiometers to measure the displacement of a line stretched horizontally on a stem due to the tree vibration in voltage. We also used accelerometers to measure sway frequencies.

In a free vibration analysis of a standing tree, the vibration of a tree was recorded at 80Hz. In this case, the peak of PSD occurred at 0.8Hz. This frequency is considered the fundamental mode of the natural frequency of the standing tree. Our value is slightly higher than 0.4-0.6Hz of Douglas-fir trees (Moore and Maguire 2005). The difference may be explained by differences in tree species and size and structure of trees.

The peak of PSD of the tree sway motion was observed on 0.7Hz in the field measurement. Although the peak of the wind velocity did not occur near the natural frequency of the standing tree, the tree obviously and strongly swayed at the natural frequency.

Keywords: Self-Induced oscillation, standing tree, strong wind, natural frequency

Characterizing spatio-temporal patterns of insect and wind-related mortality in balsam fir and spruce stands

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Mortality is the most difficult and least reliable aspect of evaluating forest growth affecting estimates of long-term sustained yield and annual allowable cut (AAC), particularly as stands enter the break-up phase. Spatiotemporal inventory data from permanent sample plots established in 1987 and remeasured every 3 years located in 50 declining balsam fir (*Abies balsamea* (L.) Mill.) and spruce (*Picea* spp.) stands were used to determine the extent of tree-to-tree interactions and their effects on individual tree mortality and stand break-up. Stands were located in the Acadian and boreal forest of New Brunswick, Canada, and had a history of recurrent spruce budworm (SBW; *Choristoneura fumiferana* Clem.) outbreaks, aerial insecticide spraying, and absence of harvesting. Since plot establishment in 1987, the dominant cause of death has shifted from SBW to wind-related causes.

Logistic regression models of individual tree mortality were generated for two analysis periods, corresponding to near the end of the SBW outbreak (1990-1992) and about 10 years following the cessation of defoliation (1999-2003). Parameters included characteristics of 657 subject trees (e.g., DBH, previous growth) and 7247 neighbours within a 5 metres search area (e.g., competition, previous wind-related mortality, crown closure). In 1999-2003, subject trees that died had search areas with lower crown closure (36% versus 50%) and three times more wind-related mortality (0.9 m^2/ha/yr versus 0.3 m^2/ha/yr) than their surviving counterparts. A secondary impact of wind-related mortality was dead tree fall collisions, which killed 1.1% of trees and damaged 1.3% of live trees.

The logistic regression model results suggest that although residual trees surviving a SBW outbreak may benefit from reduced competition for resources, increased wind exposure as a result of canopy openings render them more vulnerable to wind-related mortality. We conclude that spatially explicit datasets that incorporate past mortality would greatly improve the prediction of tree death events in stand dynamics models.

Keywords: individual tree mortality, logistic regression, wind-related mortality, spatiotemporal inventory data, spruce budworm outbreaks, tree fall damage

Some aspects of windfall and spruce beetle dynamics in sub-boreal spruce forests in central interior British Columbia

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Windthrown trees play an important role in the host-population dynamics of the spruce beetle (*Dendroctonus ruffipennis (Kirby)* (Coleoptera: Scolytidae) in spruce-fir forests in western North America. At endemic population levels, spruce beetle mainly exploit freshly windthrown trees and/or logging debris; successful attacks in live trees are rare. Increases in spruce beetle populations leading to outbreaks in live trees may be associated with increases in windfall or untreated logging debris. In British Columbia, all known spruce beetle outbreaks have followed major windthrow events or accumulations of logging debris.

We investigated temporal and spatial patterns of windthrow within mature stands and at the edge of recent cutovers on two study sites in white spruce/ subalpine fir forests in central interior B.C., as well as spruce beetle populations. Over a six year period, the average annual loss of spruce greater than 20 cm dbh was 3.73 and 1.13 $m^3ha^{-1}yr^{-1}$ on lower elevation and higher elevation sites, respectively. The higher rate of windthrow on the lower elevation site is thought to be due to wetter soils and shallower rooting. However, the volume of windfall at the stand edges adjacent to recent clearcut openings was 3.4 and 4.6 times greater than within the low and high elevation undisturbed stands, respectively. About 75% and 86% of the windthrow occurred through tipovers within the mature stand and at the stand edge, respectively, with the balance occurring through stem breakage. Windthrow occurring from stem breakage had a significantly higher frequency of stem rot. A higher proportion of larger diameter trees tipped over within the mature stand than at the stand edge, suggesting that smaller diameter trees were somewhat more protected within the mature stands. The spatial distribution of windthrown trees within the mature stands appeared to be clustered, suggesting that once an opening in the canopy was created, adjacent trees were more susceptible to windthrow. Windthrow fall direction was highly correlated with the prevailing wind direction.

Spruce beetles were found in almost all of the fresh spruce windthrow both within the mature stand, and at the stand edge. However, spruce beetle populations remained within endemic levels during the study period. This work confirms the importance of understanding windthrow dynamics to managing spruce beetle populations.

Keywords: windthrow, spruce beetle, host-insect dynamics, disturbance ecology

Flexure Wood in Hybrid Poplar

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Wind-induced sway or dynamic mechanical flexing are known to induce alterations in xylogenesis resulting in modifications in the mechanical properties, cellular properties, anatomy, chemistry and morphology of wood in a number of tree species. In a previous study in the conifer, *Abies fraseri*, the term 'flexure wood' was coined to distinguish wood formed in response to a swaying motion from that of 'normal wood' and 'compression wood'. In conifers, flexure wood has characteristics which are intermediate between normal and compression wood, including shorter tracheids, higher wood density, and an increased microfibrilar angle (MFA). In porous wood angiosperms, tension wood is the is the characteristic reaction wood formed in the gravitropic response and is characterized by fibers containing a gelatinous cell wall component which is higher in glucose content and lower in lignin content. MFA also decreases, approaching 0°. In this study, wild type and C4H::F5H/Cald5H transformed hybrid poplar (*Populus tremula* x *P. alba*, clone 717) were used to explore the effect of simulated wind sway on wood formation and chemical composition. The flexure wood of hybrid poplar is characterized by no significant change in total lignin, no significant change in sugar content, an increase in syringyl content, and an increase in MFA. Although some gelatinous fibers were observed in the stems of both control and flexed trees, the appearance of these fibers does not appear to significantly alter the total wood chemical composition. In the case of this diffuse porous species, flexure wood appears to share more in common with flexure wood in conifers than with tension wood.

This research was supported by the National Research Initiative of the USDA CSREES grant number 2005-35103-15269.

Keywords: microfibril angle, MFA, lignin, syringyl, tension wood, reaction wood

Is spiral grain a full-tree response to environmental conditions? Analysis of the literature

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Spiral grain is an anatomical wood trait: the grain of the tree is formed in a spiral or helical arrangement about a tree's axis, as opposed to developing parallel to the tree's axis. Wood users have been aware of this wood quality trait for many years, and it is known to be a cause of weakness and warp in sawn lumber, distortion and weakness in roundwood uses, and problems when it is used in veneers. As such, spiral grain has been much investigated by wood scientists, and its cause is the subject of considerable debate amongst tree physiologists, wood anatomists, geneticists, silvilculturalists and foresters. A variety of rival theories have been proffered as to its cause, but these theories might be best described as an underdetermination: the proffered hypotheses are inconsistent with each other, yet are at least partially consistent with the evidence. These theories, offered with wide variation in support within the literature, are: Coriolis effect; movement of the sun; soil condition; root development and architecture; slope and aspect; altitude; temperature; wind; prevailing wind and crown asymmetry; growth rate (including influence of fertilizer applications); reaction wood and eccentric growth patterns; stem structural damage; water distribution within the tree; genetic characteristic; and silvicultural practices. Review of much of the research conducted to investigate the various hypotheses has found a generalization with a weak correlation for each hypothesis, but this generalization also carries inherent and significant exceptions that, if regarded critically, might be seen to support one or more rival theories. This presentation seeks to present the results of a critical analysis of existing spiral grain literature and related research, and endeavours to establish whether there is a commonality of the research that would support the overall supposition that spiral grain is an environmentally induced characteristic.

Keywords: spiral grain, wood quality, environmental induction, rival theories.

Large scale winter storm damage to Swiss forests - a pattern and risk analysis

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Severe winter storms cause increasing damage to wide parts of Swiss forests, in mountainous areas as well as in the low lands. Such extra tropical cyclonal storm events have usually been termed as west winter storms without any further differentiation. In order to assess the potential risk of storms to Swiss forests, it is necessary to determine the most common storm pattern and their potential reoccurrence intervals. For a risk assessment it is also important to test if measured wind variables from automatic climate stations can be related to actual forest damage.

Therefore, records of severe damage and meteorological data for the last 150 years were used for a semi-quantitative separation into main types of west storms. Following the extraordinary strong storm Lothar (December 26, 1999), which belongs to the most common storm types in Switzerland, damaged forests had been delineated using high-resolution aerial photographs. We compared forest damage in the vicinity of the climate stations with measured wind speed, on the one hand, and modeled wind data, on the other hand. Different wind factors (maximum wind gust speed, max. 10-minute mean wind speed etc.) were tested using varying resolutions of damage data.

For the different winter storm types regional risk pattern were mapped at the cantonal level and with respect to Switzerland's topographic regions. The overlay of observed damage and measured wind and modeled wind allowed identifying wind measurements that can be used to estimate forest damage related to the winter storms.

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Keywords: windthrow risk, storm damage pattern, west storm types, winter storm history

Long-term effects on growth after windthrow of 70 million m^3 in southern Sweden

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A storm in January 2005 in southern Sweden caused great damage to forests, relics of ancient culture, buildings, the power supply, telephone communications, and transportation systems. The Swedish Forest Agency soon established that the amount of damage to forests was about 70 mill. m^3, i.e. twice the annual cut in the damaged area. To better understand the relation between wind damage and plot characteristics, a sub-sample of field measured plots in the damaged area from the Swedish National Forest Inventory were chosen for further studies. To assess damage/no damage and crown density for each plot, aerial photographs were taken of the 1721 plots. To avoid classifying newly cut plots as damaged, planned cuttings in the area were identified with help from the Swedish Forest Agency. For calculations of damage, field data for each sample plot were merged with the recorded outcome of the aerial photograph analysis. The long-term effects on growth were analyzed by comparing earlier calculations and the outcome of the present situation.

Of the analyzed area of forests, 5.6% was damaged, i.e. 272 000 hectares, with a damaged volume of ca. 66 mill. m^3. Damaged plots were typically old, had high standing volume, were dominated by Norway spruce (*Picea abies* L. Karst.), and were often newly thinned. Damaged plots indicated that 64% of the damaged area had a crown density below the limit where regeneration must take place according to the Swedish Forestry Act. In the damaged area, the growing stock after the storm was decreased by 9% giving a 1% reduction in growing stock after 100 years. During the entire 100-year period the potential cutting after the storm decreased by approximately 1%. This is a result of fewer cuttings during the first 20 years after the damage, and an increased need for thinning of the areas regenerated after the storm. However, the effects for a private forest owner can be much more serious. We conclude that data from the Swedish National Field Inventory is suitable for analyses of damage from abiotic factors such as wind.

Keywords: storm, wind damage, Swedish National Forest Inventory, risk factors, consequence analysis.

Tree regeneration and vegetation dynamics in windthrow forest gaps from French integrated monitoring sites

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Following the 1999 storms, a monitoring network was set up in for the blown down stands where a regeneration problem was suspected. The objective of the network, established in the north-eastern France (Lorraine/Alsace region) and later in other regions, is to study natural vegetation dynamics and young tree recruitment on a large geographical scale and their time-course over a period of 20 years without any sylvicultural operation. The network is present by 181 permanent units in large gaps (>2ha) and 107 units in small gaps (ranging from 300m² to 1ha). At the present time, one set of data has been collected in the small gap units and two in the large gap. Tree recruitment and vegetation dynamics have been analysed from different perspectives: geographical (i: between site), site (ii: intra site) and time (iii).

i) Principal component analysis shows that between-site variation is controlled by trophic levels and previous stand characteristics. Recruitment of valuable tree species was abundant across a wide range of gap sizes, trophic levels and present surrounding stand characteristics or previous stand characteristics. This was observed for most sites except those on calcareous plateau that previously had conifer plantations. The floristic variability appeared also to be closely related to the soil pH and more slightly to light gradient and C/N factor.

ii) Intra site variation shows that oak, hornbeam and maple prefer microsites close to the gap border. However, their stem growth is higher at the gap centre.

iii) The time study in the large gaps shows that it is possible to make a first silvicultural diagnostic (seedling density, and tree species composition) 3 years after the storm, since most seedlings are established just after the canopy opening. However, the frequency and the abundance of most herbaceous species still show important changes 6 years after the storm event.

These first results reveal that vegetation dynamic and tree recruitment after a major disturbance such as a high intensity wind storm appear to be controlled firstly by soil pH, and at a lower level by light gradient and the characteristics of the previous stand. They also indicate the existence of a seedling establishment pattern within the gaps.

Keywords: vegetation dynamic, natural regeneration, monitoring, windthrow gap, soil pH, light; stand characteristics

Wind loading on trees in two nearby stands with different structure

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In the literature it is often stated that forests which are uneven aged and structured in height are more stable than even-aged mono-cultures. However, the evidence tends to be anecdotal or based on post damage surveys that always have compounding factors. A field experiment was carried out to investigate the wind loading on trees in two adjacent locationss where the stand structure was different. One stand consisted of mature larch (*Larix decidua* P. Mill.) of about 25m height with no understorey. The second stand which was 50m away had the same overstorey but with an understorey of Larch and Sitka spruce (*Picea sitchensis* (Bong.) Carr.), of about 12m height.

30m masts were erected in each stand equipped with cup anemometers to measure the wind profiles in each canopy. The wind loading on the trees in the stand was measured with high temporal resolution using strain gauges. In total nine trees were measured simultaneously. Two of these trees were located in the stand with no understorey four overstorey trees were monitored in the stand with an understorey and the remaining three trees were in the understorey.

The experiment ran from March to November 2006. The data allow us to analyse, whether there is a difference in the wind loading on the overstorey trees in the two stands and if the understorey has a significant impact on the wind profile, which might help increase the stability of the stand.

The results of this experiment will help in understanding wind and tree interaction at a stand level. As a next step the results will be implemented into the ForestGALES forest wind-risk model to allow make it to work with stands that are managed under a continuous cover regime.

Keywords: continuous cover forestry, stand structure, field experiment, ForestGALES

Windthrow in Tasmania, Australia: issues, implications and management

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In Tasmania, Australia, concern regarding the finite nature of the native hardwood forest resource has lead to high levels of reservation. Those areas set aside for timber production are managed increasingly under a range of variable and/or aggregated retention systems. These aim to reduce visual impacts of traditional clearfall, burn and sow (CBS) operations, whilst maintaining and/or enhancing biodiversity.

To augment hardwood timber supplies from native forests, a eucalypt plantation estate is managed for pulp and other high-value solid wood products (sawn timber and veneer), grown over 15-25 yr rotations. The latter require considerable investment early in the rotation (site preparation, establishment, and pruning), and later, a single heavy thinning to ensure adequate piece size.

Situated between latitudes 40^{o} and 44^{o}, the 'roaring 40's', where strong winds and heavy rainfalls prevail, Tasmania is characterised by coastal zones, open plains and mountainous terrain. Soils vary markedly in their physical properties; shallow stony soils of low mechanical strength or those characterised by poor drainage and/or hardpans are common.

The resulting climatic, site and silvicultural conditions have meant that forest managers need to address the issue of wind disturbance. This includes damage to native forest aggregates and associated under-story species, or windthrow occurring in plantation forests subsequent to intensive thinning operations. In addition, there is growing interest in the relationship between exposure, stem form and wood quality. Exposure can result in stem eccentricity and sweep, whilst affecting internal wood properties, each with consequences for log processing and product quality.

This paper describes key wind-related issues facing forest managers in Tasmania, existing management strategies, and also, results from preliminary investigations of the relationship between exposure, stem form and wood quality.

Keywords: windthrow, exposure, stem form and wood quality, Tasmania, Australia.

Forest response to natural disturbance: Change in structure and diversity on a North Carolina Piedmont forest in response to catastrophic wind events

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Large hurricanes have profound impacts on temperate forests, but owing to their infrequent nature these effects rarely have been examined in detail. In 1996 Hurricane Fran significantly damaged many long-term census plots in Duke Forest in Piedmont North Carolina, thereby providing a unique research opportunity. We combined over 20 years of pre-hurricane and five years of post-hurricane data on individual trees, seedlings and saplings to determine how hurricanes affect forest structure, diversity, and succession. Several plots severely damaged in 1954 by Hurricane Hazel allowed comparison of recovery patterns and evaluation of long-term effects. We first assessed hurricane-induced structural and compositional changes and evaluated mortality risk factors. Fran caused widespread uprooting of large canopy trees. Stand-level damage severity varied substantially across the distributed network of permanent plots. Hurricane-induced mortality of large-size hardwoods was often delayed. Although tree damage was primarily caused by winds and rainfall, damage was also found to be correlated with site exposure, topographical position, tree size, and species susceptibility to wind. Next, to test the hypothesis that hurricanes maintain local tree diversity through increased heterogeneity and resource availability we examined changes in understory survivorship, recruitment, and growth. The understory experienced highly variable population impacts as well as subtle changes in tree diversity. Following Fran both seedlings and saplings exhibited an immediate drop in stem density followed by a rebound. In addition, the hurricane resulted in release of established, shade-intolerant or mid-tolerant seedlings and saplings, thereby potentially increasing future canopy tree diversity. Finally, we assessed whether hurricanes have long-term effects on tree diversity and succession. Past hurricanes appear to have accelerating succession in even-aged pine stands toward a later, hardwood-dominated successional stage, and to have shifted the hardwood forests toward more diverse composition, although with increasing dominance of red maple. We concluded that large, infrequent hurricanes play an important role in shaping forest structure and maintaining tree diversity in the Piedmont region. However, the effects on tree composition and diversity vary greatly and depend on local damage severity, pre-hurricane stand characteristics, and the temporal and spatial scales at which the changes are observed.

Key words: catastrophic winds, hurricanes, forest damage, stand recovery and dynamics, intermediate disturbance, complex effects, long-term impacts, within-stand heterogeneity, Duke Forest, Piedmont North Carolina, temperate forest.

Wind damages to Scots pine and Norway spruce on Polish lowland – spatial analyses and silvicultural approach

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The aim of the study was to analyse a particular cases of windthrow that occurred in Polish State Forests in 2002-2004. The research was focused on Scots pine and Norway spruce as a species the most threatened with this kind of damage.On the plots, basic biometric features of all standing trees were measured. All broken and uprooted trees were listed. Spatial analyses of stand structure were carried out with consideration both live and damaged trees. The K(t) Ripley method [in L(t) modification] of pattern determination of specimen distribution was applied.

The results show complexity of issues regarding building the stand resistance to damages. Biometric data indicate the great importance of slenderness and relative crown length in this process.

According to spatial analyses, in spruce and pine stands of middle and old age classes, random model of distribution prevails. In some plots it shows tendency to change into cluster pattern due to damages. It confirms thesis that remaining of tree groups of high dimensions is of a great importance in shaping the wind resistance.

Comparison of results derived from light and heavy damaged plots confirms thesis that in spruce stands of older age classes, the individual stability is of a lower importance than group stability.

The case studies of both species proved importance of forest edge structure for minimization of damages. Trees growing at the edge shall be characterized by low slenderness, but they shall not be branched too low, because of escalation of turbulent air movements causing damages behind the edge.

Achieved results show that the best way of wind damage prevention are strong cuttings in young stands and light thinnings or avoiding of them in older stands, especially in zones of medium and high danger. Maintenance of spatial order is of a great importance too, due to limitation wind entrance inside the forest.

Keywords: Scots pine, Norway spruce, thinning, spatial forest structure, windthrow

The gustiness of wind downstream of a forest edge

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Assuming a spatially uniform vegetation density within the entire forest volume, a transition from open land to forest may be regarded as a porous forward facing step submerged in a turbulent boundary layer. According to this simplification, the flow across a forest edge was modeled in an atmospheric wind tunnel using a layer of an open-pored permeable polyurethane foam as vegetation model.

Single- and two-point measurements were carried out using both laser Doppler velocimetry and hot wire technique. Particular attention was paid to the dynamics of the shear layer which is formed immediately behind the edge and separates the decelerated air which has penetrated the forest edge from the free flow above. Turbulent diffusion and, thus, the vertical growth of this layer is mainly driven by the oncoming boundary layer turbulence. Very close to the edge, in the early stadium of development of the shear layer, it could be observed that the actual mixing layer is formed by a thin vertically flapping mixing layer. Time series of two point measurements, taken simultaneously at a detection point and at several points in the remainder of the flow field, were examined using a variable interval time averaging method (VITA). It could be shown that oncoming eddies of the same size as the forest height are mainly responsible for the flapping movement. The flapping implies a highly anisotropic turbulence with fluctuations much stronger in the horizontal than in the vertical. As already stated in previous works, further downstream energy is fed into the vertical motions by the return-to-isotropy mechanism.

For the case of real forests it is suggested that extreme loads on trees at a certain distance from the edge could be the consequence of discrete eddies which are contained in the upstream boundary layer and which might result in a violent downburst of air into the forest as they are distorted by the presence of the forest edge. It will be discussed in how far the density of the forest, the roughness conditions of the upstream boundary layer and the shape of the forest edge might have an influence on the position and magnitude of the extreme wind loads.

Keywords: forest edge, permeability, surface mounted obstacle, windthrow, variable interval time averaging

Tree/stand characteristics and snow/wind induced damage in montane secondary forests of Northeastern China

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Forest damage induced by snow/wind is a serious disturbance concerning forest ecology and management. When the storm intensity under some thresholds, the pre-storm forest composition and structure may partially determine the pattern of damage and leave biological legacies, which may in turn affect recovery processes. Special attention is paid on the response differences among tree species, compositions and stand structures to the snow/wind damage, which occurred in 2003 affecting about 1 0000 ha of montane deciduous secondary forests in Qingyuan of eastern Liaoning Province, northeastern China. Individual tree traits such as species, diameter at breast height (DBH) and tree height (H); stand characteristics including tree species composition, stem density, canopy openness and stratification influenced both damage modes (damage vs. undamage) and damage types (uprooting, breakage and bending). The canopy species were commonly damaged more easily than the sub-canopy species. Differences in tree species' susceptibility to the snow/wind damage were found for the 8 major tree species. For the canopy species, *Betula costata* exhibited the most uprooting, bending and overall damage; *Quercus mongolica* showed the highest breakage (both stem breakage and canopy damage); whereas, *Fraxinus mandshurica* and *Juglans mandshurica* exhibited the least overall damage. For the sub-canopy species, *Acer pseudo-sieboldianum* exhibited the least breakage and uprooting. Larger size and higher taper (H/DBH) trees were susceptible to breakage and uprooting, contrariety trees were susceptible to bending. The stand overall damage was positively related to the composition of dominant tree species and the stem density. The stand consisted of dominant species of *B. costata* or/and *Q. mongolica* exhibited the most breakage, uprooting, and overall damage. Stand breakage was found closely related to the importance values (IV) of *B. costata* and *J. mandshurica*, i.e., stands with higher *B. costata* IV or lower *J. mandshurica* IV were susceptible to breakage. Bending damage increased with increment of IV values of *B. costata*, *A. pseudo-sieboldianum* and *A. tegmentosum*. The importance of stand density in determining resistance to snow/wind damage indicated that the densely populated stand exhibited less overall damage.

Keywords: snow/wind damage, montane secondary forest, stand characteristics

POSTER PRESENTATIONS

Competition indices as a measure of wind loading on individual trees in a forest stand

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The wind loading a solitary tree has to withstand is a function of the wind profile, crown area and crown drag coefficient. In a forest stand, the relationship is affected by the presence of neighbouring trees which influence the wind profile and increase the damping due to crown clashing. For this reason, a dominant tree has to withstand much higher loads than a suppressed tree which profits from the shelter of its bigger neighbours.

This level of complexity is currently not accounted for in predictions of windthrow risk because wind and trees interactions are modelled at the stand level. As silvicultural practices in the UK move towards the use of continuous cover forestry (CCF), which leads to more irregular stand structures, there is a need to predict wind loading at the individual tree scale. Our hypothesis is that competition indices developed to estimate the amount of light and nutrients available for trees in a stand can also be used to quantify the wind loading on a single tree basis.

A field experiment was carried out in 2005 in a mature Sitka spruce forest managed under CCF in North Wales. The wind profile in the stand was monitored using a 30-m mast mounted with eight anemometers and the bending moment at the base of nine neighbouring trees was measured simultaneously with a high temporal resolution. The nine experimental trees cover a wide range of competitive status.

The aptitude of several indices (Schuetz, Hegyi, etc) to explain the wind loading each tree has to withstand was examined. Results showed that this approach can help predict an important proportion of the variation in wind loading, with several indices giving similar predictions. Improvements in the predictions may be achieved if the competition coming from a neighbour can be weighted as a function of its position in relation to the prevailing wind direction. The advantage of our approach lies in the fact that the output of growth simulators can be used to provide competition indices and hence predict individual tree wind loading as the stand matures. This also allows an assessment of how different thinning strategies may affect the vulnerability of the remaining trees.

Keywords: windthrow risk, wind risk modelling, irregular stands, competition indices

Relating blowdown to tree and stand level characteristics following a harvest inspired by an eastern spruce budworm (*Choristoneura fumiferana*) outbreak

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Partial harvest prescriptions emulating natural disturbance can be susceptible to wind damage. Beginning in 2002, three areas totaling 2600 ha on the J.D. Irving, Ltd. Black Brook District in Northwestern New Brunswick were treated with a harvest prescription inspired by an uncontrolled spruce budworm (*Choristoneura fumiferana*) outbreak. The harvest prescription aimed to create stand structure that would reflect expected mortality of host species and resulted in the harvest of 9 out of 10 balsam fir (*Abies balsamea*) and 6 out of 10 spruce (*Picea* sp.) trees. A network of permanent sample plots (PSPs), including controls, was installed prior to the harvest.

Following the completion of the harvest treatment, blowdown began to occur. From 2004 until 2006, trees in the PSPs were assigned to one of four damage classes: undamaged, uprooted, stem breakage, or crown damage. Untreated plots (23) have sustained <1% basal area (BA) wind damage, versus an average of 23% in treated plots (63). Forty-three percent of treated plots were in the 0-10% BA damage class, 29% sustained 11-30% damage, and the remaining 28% of the plots had damage greater than 30%. Tree level variables including diameter at breast height (dbh), height, slenderness and live crown ratio were analyzed using general linear models and compared to the occurrence and type of damage. Trees that experienced stem breakage or uprooted were significantly smaller (dbh and height) than undamaged trees, indicating that trees that were sheltered prior to harvest were more susceptible to damage. Regression analyses compared the percent BA blowdown to plot level measures such as BA removed, species composition, topographical exposure, average stand height and dbh. Percent balsam fir and BA removed were positively related to percent BA blowdown in plots that were harvested in 2002. The spatial arrangement of plots by damage severity was analyzed to determine possible geographically related damage.

Harvesting based on natural disturbance aims to provide residual stand structures and a landscape mosaic similar to that resulting from the natural disturbance. In order to function correctly the occurrence of blowdown following the harvest should be comparable to that occurring after a natural spruce budworm outbreak.

Keywords: natural disturbance, partial harvest, spruce budworm, blowdown

Wind Direction and effect of Tree Lean on Coarse Woody Debris Production

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The natural fall of trees in riparian areas is an important source of coarse woody debris for mountains streams, improving fish habitat and influencing stream morphology. Existing models consider tha probability of coarse woody debris entering a stream channel based upon trees having a random direction of fall without consideration of tree lean or wind direction. This research presents (1) the results of a field study document tree lean of conifers near streams in two stands in the Oregon´s Coast Range and (2) a physical and probabilistic model to estimate the probability of a tree falling into the stream including the effect of tree lean and wind direction.

The measurement of 200 conifers along two creeks located in McDonald Forest found that tree lean varied from 1 to 34 percent uphill and 1 to 29 percent downhill on slopes of 1 to 88 percent. Approximately 75 percent of the trees leaned downhill and 25 percent of the trees leaned uphill.

A physical model was developed for calculating the critical wind speed required to overturn a tree. This critical wind speed is a function of maximun resisting moment of the root structure, crown cross sectional area, initial tree lean and the angle formed between wind direction and lean direction on the horizontal plane.

A probabilistic model was developed for determining the probability that a tree could fall a reach the stream. This probability is a function of exceedance probability for a particular period of time, wind direction probability, tree location and tree height.

The models were applied to old-growth coniferous stands. Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) trees were selected to illustrate how the models can be used. Results of this study indicate that tree lean is not a major factor with respect to influencing tree blowdown for the range of tree lean data collected from coniferous trees along streams in the study area. Tree lean could be a major factor if it was greater than that observed in this study.

Keywords: wind speed, windthrow risk, coarse woody debris.

Mangrove community recovery following Hurricane Hattie, Turneffe Atoll, Belize

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Coral atolls and their terrestrial and marine ecosystems are a key component of tropical biodiversity, are rich in marine resources and provide opportunities for recreation and tourism [1]. Mangroves are an integral component of these ecosystems and are unique amongst vegetation communities in that they span the marine and terrestrial environment. In this coastal position, mangroves bear the full brunt of hurricanes and tropical storms which are a frequent form of disturbance in these latitudes [2]. In order to guide conservation and management of these ecosystems we need to better understand the processes that underlie ecosystem productivity and resilience.

In October 1961, Hurricane Hattie hit Turneffe Atoll off the coast of Belize, Central America. This category 5 hurricane destroyed entire islands as well as most of the vegetation and human habitation. We have detailed maps and data of the vegetation, geomorphological features, and human activities of islands from Turneffe Atoll collected by Dr. David Stoddart immediately before and after Hurricane Hattie. We have also assembled aerial imagery taken by the RAF from the 1940's-1970's, satellite imagery and recent low elevation aerial photography. We are using these datasets to prepare maps showing island and vegetation condition over time. We are establishing transects and plots in the field to document vegetation and substrate composition and productivity.

Since Hattie, reef crest islands have reformed, albeit in different shapes, and both fringing mangroves and littoral vegetation communities have re-established. We are taking a landscape ecology approach to characterizing vegetation patterns and fitting empirical models to evaluate the role of prior human disturbance, post-hurricane condition, reef configuration and foreshore bathymetry, substrate composition, and proximity to larger islands in the rate and nature of island stabilization and vegetation re-establishment.

Keywords: hurricanes, island geomorphology, mangroves, vegetation community dynamics

Two-point statistics of turbulent flow in the canopy layer

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Unlike detailed CFD and LES runs simulating flow and turbulence in forest canopies, field and laboratory studies are not able to capture instantaneously the 3d-nature of turbulent fluctuations – neither above nor inside forests. Nevertheless, there is need to validate theories and models describing the 3d-structure of turbulence with field and laboratory data. Today's preferred turbulence sensors record time series of turbulent fluctuations at a given location in the flow field. In many situations we use a single sensor and implicitly apply Taylor's frozen turbulence hypothesis to 'translate' statistics measured in the time domain to space. An example is the calculation of Eulerian one-point length scales ('eddy sizes') from autocorrelation functions in the time domain. However in the canopy layer, core assumptions of Taylor's hypothesis fail.

The field experiment HX06 was designed to quantify rarely measured spatial statistics, e.g. two-point length-scales. The term 'two-point' refers to the fact that we do not make use of Taylor's frozen turbulence hypothesis but use spatially separated sensors. Twelve ultrasonic anemometer-thermometers were arrayed in the trunk space of a Scots Pine forest at Hartheim Research Station in Germany. Sensors were mounted at a uniform height of z = 2 m above ground ($z/h = 0.13$, h is canopy height) and aligned in a cross-shaped set-up with increasing inter-sensor separation from 4 to 192 m. Additionally, 6 fast CO_2/H_2O analyzers were co-located. All sensors were sampled at 20Hz over 30 days in spring 2006.

Auto-correlations for different time lags and pairs of sensor separations were calculated for all measured fluctuations. The values underline that dominating turbulent structures in the canopy layer are transported much faster than the average Eulerian velocity u at given depth. The speed of transport of the dominating structures – the convection velocity u_c – is an order of magnitude higher compared to u ($u_c = 7.7\ u$). The explanation for this significant discrepancy – an hence the failure of Taylor's hypothesis – has been discussed in many previous studies: the dominating turbulence structures originate from the higher velocity stream above the canopy and penetrate with increased turbulent kinetic energy (TKE) down into the canopy. Hence, dominating TKE and most scalar fluctuations (e.g. temperature) in a forest canopy are not locally produced but imported from aloft.

Keywords: Turbulence, two-point length scales, Taylor's hypothesis, canopy layer.

Empirical wind damage model based on wind storm of January 2005 in Latvia

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During wind storm of January 8/9 2005 in Latvia were damaged more than 7.8 million m3 of standing volume. Goal of this study was to get empirical information on wind damage in Latvia during storm, and find out most important factors influencing wind risk in Latvia.

Map of the wind speed in the gusts during storm is prepared by Swedish Meteorological and Hydrological Institute based on Mesoscale Analysis System MESAN.

As there was clear wind speed gradient from W, NW to E, SE over the territory of Latvia (from 40 ms^{-1} in down to 15m s^{-1} in gusts accordingly), one km^2 assessment areas were established in the geometric center of each forest districts (n=171). All forest stands which fit in the squares, where visited, described and wind damage rate assessed during July to September 2005, as well information about cutting activities during last 10 years were collected - totally assessed 8517 stands. Forest maps and relief (from old Soviet military maps) at scale 1:10 000 of 75 squares and their vicinity at least 500m (4 km^2 per assessment area) were digitized.

For all stands was calculated mean aspect, height above sea level, relative height of tree tops above neighboring stands using ArcGIS 8.3. extension Spatial analyst.

Binary logistic regression (SPSS 14) used to calculate factors influencing damage rate. Only Scots pine, Norway spruce and Birch spp. were used in analysis. Classification is correct in 67%. Nagelkerke R^2 =0.123. Most important (siginificant) factors are species, height of dominant species, aspect, time since previous cutting, wind speed, type of landcover neighboring in W direction.

Keywords: Wind storm January 2005, wind damage modeling.

Coastal wind degradation – an approach of utilizing mangrove nursery specie for protection study in Xinhui coastal district, Guangdong Province of China

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Mangrove wetland resources utilization is an important aspect of coastal environment to discuss. This study identifies mangrove direct utilization under coastal protection and wetland biodiversity utilization and conservation. Mangrove acts as the interface between land and sea that becomes an ecotone structure and provides natural protection of coastlines from erosion, storm damage, and wave action, by way of buffers and catchments of alluvial materials. The study site was in Xinhui, Jianmen city of Guangdong province, which lies along the coastal stretch of the South China Sea and experiences yearly devastating wind erosion. The area is covered with a mangrove grassland species (*Acanthus ilicifolius* Linn), which for the purpose of environmental benefits were cleared and restored with six week, reared viable nursery of adopted species (*Sennoratia caseloris* Engl.) that becomes strategic approach. This study attracted constructive criticism of biodiversity conservation and utilization to which it was designed to integrate issues of coastal protection by the application of restoration using a non-native specie nursery experiment - damage mitigation/ sustenance and management to reduce wind erosion (damage).

Geochemical analysis of the restoration site conforms to mangrove coastal wetland nutrient base. *In the face of mechanical world man shall not lose his skill,* Leaf Area Index analysis was carried out on a manual approach across the four-sample plot taking at random every week across months of October 2004 to May 2005. Statistically, months of October and November, indicates a stabilization month of 0.78 ± 0.15 and 0.79 ± 0.17 respectively showing no statistical difference in growth and biogeochemical parameters, third month (December) was 0.95 ± 0.14 indicating difference against previous months, (January) was 1.10 ± 0.16, (February) 1.32 ± 0.18, (March) 2.05 ± 0.28, (April) 2.85 ± 0.23, (May) 4.35 ± 0.19, respectively indicating rapid growth progression and soil nutrient enhancement. Growth variation across months of April and May (2.85 and 4.35) compared with lower months indicates steady growth. Mean sample size on growth indicates non-significant difference in growth, while January to May (0.4258 ± 0.03, 1.38 ± 0.06, 2.2187 ± 0.09, 2.96 ± 0.26 and 4.75 ± 0.35 respectively are comparably of significant difference. With regards to LAI evaluation, monthly rate of evaluation across the sample plots indicate a low percentage mortality rate (7%), and an average (18%) of dead/stressed nursery at site and survival (93%) success in utilization of the species for coastal wetland restoration and windbreak purposes. The long-term environmental benefit is achieved through the expected protective canopy.

Mechanic of eucalypts trees under wind loading

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Under wind loading Eucalypts planted trees in a well done management, in terms of growth rate, break in between 1.2 and 2, m above ground, depending on their stem taper. Also they neither break when they are under two nor above three year old. That happens because the trees are tall enough to have their crown exposed to strong winds and aren´t large enough to the minimum required moment of inertia to take down the bending stress. The model we built up to calculate the tree as a cantilever beam with variable cross section base on mechanical bending tests of many trees right "in situ" showed they cannot carry the maximum moment imposed by the wind. Clones based stands generally break more easily than one seedling from seed based do because of their higher amount of cellulose content in the wood as they are just improved for. Those trees have more stiffness and have little deflection so that they remain under highest wind load. Trees obtained from seed seedling are more flexible so that they bend and escape from the wind effect, but in some case they remain bent after storm. The work permit to suggest better management strategy for combining the best growth rate, wood quality and with wind effect.

Modeling windthrow in riparian zones in Newfoundland

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After logging, remnant timber in riparian zones is vulnerable to wind damage, potentially impacting riparian zone functionality. Recently an interdisciplinary panel was formed in Newfoundland to investigate options for managing timber in riparian zones while maintaining riparian zone integrity. The panel's goal was to identify the extent of windthrow damage in riparian forests and develop a predictive model of vulnerability using high resolution wet-areas mapping, Anemoscope wind modelling, and tree, neighbourhood, and other stand-level attributes. In the summer of 2006 I surveyed 45 riparian zones in western Newfoundland, characterized by balsam fir (*Abies balsamea*) and complex terrain, and 7 in the central regions, dominated by black spruce (*Picea mariana*) on primarily flat terrain. Of the total 18,666 trees measured, 1803 were windthrown. Proportion of windthrown stems/ha ranged from 0.0 – 0.62 (mean = 0.11). Preliminary results suggest species, height, and presence of rot influenced tree vulnerability. Balsam fir experienced higher windthrow vulnerability (0.12) than black spruce (0.08) and the mean DBH for windthrown and standing trees was 17.5 cm and 14.2 cm, respectively. Proportion of trees that failed at the root, stem, and crown were 0.76, 0.22, and 0.02, respectively. Root, brown cubicle, and white string rot were observed in 24%, 19%, and 4% of windthrown trees, respectively. Seventy-eight percent of fallen trees were located on the outer riparian edge; mean windthrow for edge transects was 18% versus 6% for inner transects. Stand densities ranged from 400 stems/ha - 4000 stems/ha; damage was inversely correlated with density. A high-resolution wet areas map, a relatively new forest management tool designed to locate potential wet spots for better forest planning will be used to determine the depth to the water table for each windthrown tree. Wind variables will be assessed using Anemoscope, which is capable of modeling wind flow at scales comparable to digital elevation mapping. A generalized linear modeling approach will be used to construct a windthrow risk map for riparian forests in Newfoundland.

Keywords: Anemoscope wind model, riparian zone integrity, wet areas mapping, windthrow modeling

Influence of trees in urban street canyons on the dispersion of vehicle exhausts

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The effective dilution and removal of traffic released pollutants is of extreme significance for the health of people living in cities. Pollutant dispersion processes in narrow urban street canyons are dominated by vortex structures, generated by the interaction of buildings with the atmospheric wind and are well understood for empty, obstacle-free street canyons. However, to what extend the natural ventilation is modified or limited by an avenue-like tree planting inside the canyon has not been investigated so far and is the topic of the present study.

In boundary layer wind tunnel studies, pollutant dispersion processes have been investigated inside an isolated urban street canyon model with various avenue-like tree planting configurations. The model setup consists of two parallel rows of houses forming the canyon and one row of model trees placed at the canyon center axis. A tracer gas emitting line source at street level was used to simulate vehicle exhaust emissions. Additionally, the influence of traffic-induced turbulence on the exhaust dispersion was simulated by means of small plates mounted on belts rotating along the street axis.

Flow and concentration measurements have been performed in the presence of a simulated atmospheric boundary layer wind approaching perpendicular to the street axis. Significant impacts of tree plantings on the pollutant dispersion inside the urban street canyon were found. Vortex structures typical for empty street canyons were inhibited to develop or considerably reduced in strength. High rises in pollutant concentration were observed in the canyon middle part at the leeward wall and at the street ends towards the neighboring intersections. However, paying attention to some design rules concerning the planting, like providing sufficient large tree spacing and limiting the crown size, the problem of pollutant concentration increases can be essentially mitigated. Examples and guidelines for planting configurations allowing for sufficient natural ventilation and adequate pollutant dispersion will be presented.

Keywords: urban trees, pollutant dispersion, urban street canyon, urban air quality, traffic exhausts, suppression of canyon vortex

Assessing storm events and reforestation in the Ural, Russia

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Windthrow is an important factor in forest. Management and ecosystem stability are closely related. The topic is worked upon in a joint Russian-Swiss context, trying to compare conditions in Switzerland and the Ural mountain range, understanding general system behaviour, and to give recommendations to forest management.

Parts of the problem include:

1. Description of the data for the study (Plots on a regular grid, of xx m^2 area, with management variants, plus unaffected forest, adjacent to each other), which allow for first evaluation of the choice of variables for observation, strategies of reforestation management (clearance, planting, doing neither).

2. Statistical analysis of wind events, study of wind events as a random processes, characterization of types.

3. Analysis of the initial stage of reforestation under the different regimes of management, dynamics of tree density and tree height.

4. Modelling of early reforestation, competition between grass and trees, spatial distribution of trees.

5. To simulate long-term changes in ecosystems and forest stands after windthrow (50 to 100 yr)

We observed that in the Ural planting is not necessary for the success of regeneration, because natural undergrowth is sufficiently present, in contrast to Switzerland. However, the dynamics of regeneration do depend on the type of management.

Our study of wind records in Russia and in Switzerland suggest that during the last decades storm intensity, duration, recurrence frequency and their variations have decreased in the Ural, in contrast to Switzerland. First simulations of long term forest development indicate that late successional species are favoured by decreasing storm risk, but also that this effect may be masked by species changes due to warming.

Thanks to UralHydroMet, Ekaterinburg, Russia, for the meteorological data. This work is sponsored by grant SCOPES Nr. IB74A0-110950 of the Swiss National Fund

Keywords:, windthrow, weather conditions, succession, long- and short-term models, landscape model, reforestation management, recommendations

Windthrow on Haida Gwaii

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Haida Gwaii is a fairly unique place in the world, but especially when it comes to windthrow. This is because we have some of the highest winds known in coastal BC, very steep high ridges, very exposed low lying coastal plains areas, and wet, cool conditions. The poster we are preparing will outline these unique conditions as well as the different types of windthrow i.e. uprooting and trunk breakage. It will also display different examples throughout the islands of poor retention and block design, and will show how these factors can have devastating effects on forested boundary edges, retention areas, riparian zones, and Haida Cultural and archaeological values such as Monumentals, Cultural Plants, and Culturally Modified Trees. We will also be acknowledging the effects it can have on birds nesting and foraging areas as well as the pros and cons windthrow can bring to bears and there dens.

Digitizing as a tool for modeling the 3D architecture of tree crowns

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The 3D architecture of tree crowns is a central component in the interaction between wind and trees. Detailed measurements of tree architecture can be utilized in airflow models to better understand the behavior of the branch system under wind load. This presentation demonstrates reconstructing the full 3D architecture of Scots pine crowns using a model that was parameterized by digitizing the 3D architecture of a number of sample branches along the crowns of the study trees. Measurements on the number and size of needles, as well as on the dimensions of branch and stem segments at various parts of the sample branches were also made. These measurements enabled reconstructing the 3D structure of whole trees by using information only on the length and height of the remaining branches within the crown.

Keywords: tree architecture, damage prediction, modeling wind and tree interaction

Species influence to the mechanism of wind damage in mixed stands.

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Several windstorms have damaged Estonian forests in recent years. The data was collected from plots in storm-damaged forests in eastern Estonia, which experienced storms in July 2001. We also used aerial photographs and digital soil maps to find out factors that may cause the blow down of the stand. Permanent sample plots were established randomly on small nature reserve, where coarse woody debris was left untouched after catastrophic disturbance event. The average age of the stands was more than 100 years and no intensive management was done. All stands were affected by storm (younger stands less, older stands more) and more than half of the area was blown down completely.

European aspen (*Populus tremula* L.) was the species most prone to uprooting (59% of stems) and black alder [Alnus glutinosa (L.) J. Gaertn.] was most likely to have stem breakage (82% of stems). The proportion of uprooting and stem breakage was relatively even between the Norway spruce (*Picea abies* L. Karst.) and silver birch (*Betula pendula* Roth).

Soil conditions had no significant importance for blowing down the stand. All soils of the studied plots were wet.

Important factor for a stand to be blown down is available open space close to it and wind direction (most blow down on the downwind edge of the stand). Usually we see in Scandinavia, that the first tree species what will be blown down is spruce, but in this case storm occurred in summer and first blew down all old aspen trees. Old aspen trees, with large/massive crowns were more vulnerable to windthrow than trees with smaller open crowns. After some gaps and corridors were created in the stand (fallen aspens), entire stand (spruces, birches and alders) was blown down.

Assessment of *Eucalyptus* clones tolerance to storms by means of wood characteristics

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Summer storms have caused serious damage in *Eucalyptus* plantations at several regions in Brazil. At the Vale do Rio Doce, Minas Gerais State, it has been related that the tolerance of the trees to the storms depends on both the genetic material and the environment where they grow. It has been also reported that the damages mostly occur when the trees are twenty-four months old. the objective of this work was to evaluate the differences in wood basic density and in mechanical properties of four two-years-old clones of *Eucalyptus* cultivated on slopped and on flat land, in such way to contribute for the explanation of the behaviour of their trees face to storms. The mechanical properties were the resistance and the modulus of elasticity to the compression parallel to the grain, modulus of rupture and modulus of elasticity in static bending. The evaluation of the properties was made in samples cut in each metre along the stem, in an extension of 10 meters. The results showed that the effect of clone was highly significant for all evaluated characteristics. The effect of topography (slopped or flat land) was only non-significant for basic density and compression strength parallel to the grain; higher values of BD were observed for slopped areas, except for one of the clones; for all mechanical properties the values were higher in slopped land, except for one of the clones, which did not present difference between slopped and flat land; the tolerance of the trees to the storms can not be well explained by based density, however, the tolerance showed to be reasonably dependant from the mechanical properties through positive and linear equations, with coefficients of determination changing from 44.1% (modulus of rupture) to 53.7% (modulus of elasticity in static bending).

Keywords: basic density, compression parallel to the grain, static bending, wood, *Eucalyptus,* storm.

Windthrow disturbances slow down the local succession in a sub-alpine coniferous forest of northern Japan

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Successional replacement of pioneer *Picea glehnii* by late-successional *Abies sachalinensis* in a sub-alpine coniferous forest was investigated on the Shiretoko Peninsula, northern Japan, where constant snow cover is present between November and April with maximum depth 1-1.5 m, and strong prevailing winds blow from the northwest in winter with the annual maximum wind velocity of 25-30 m/s. In addition, typhoons usually occur once every 3-5 years in September or October. Over an 11-year study period (1995–2006), the two conifer species showed contrasting modal changes in patterns of tree death with increasing diameter. No *P. glehnii* of small diameter (<8 cm) were killed by stem breakage, while almost all large-diameter (>32 cm) *P. glehnii* that died during the study were killed by stem breakage. Mortality owing to stem breakage was high in *A. sachalinensis* of small diameter (<16 cm), but decreased in trees of large-diameter (>16 cm). For both species, the probability of stem breakage at a given diameter was positively associated with crown silhouette, crown projection area, and the lowest branch height, but was not associated with the stem slenderness ratio. During successional replacement, both species increased in initial growth rate and decreased in size-dependency of growth in canopy gaps. These plastic growth responses were more prominent in *P. glehnii* than in *A. sachalinensis*. The long-term effects of wind and snow disturbances were examined by individual-based simulations that were determined by 11-year repeated measurements of tree demography (growth, mortality and recruitment rates). Disturbance frequency was the most important predictor of species composition in the simulations, and windstorms were more important than snowfall in terms of disturbance intensity. When windthrow disturbances are locally frequent because of the direction and pitch of the topography, pioneer *P. glehnii* stands may persist for many years. These results were confirmed by wind modeling and vegetation changes in satellite images from 1985 to 2001 in a 4-km^2 forested area on the Shiretoko Peninsula.

Keywords: individual-based simulation, plant biomechanics, satellite image, tree demography, wind modeling

A computer simulation of windthrow, salvage, and forest regeneration

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We have assembled a computer simulation of wind disturbance and forest regeneration, with the goal of making available a tool to guide both research and management. Our simulation is a fully spatially explicit, individual-based model that simulates growth, survival, mortality, and fecundity for all tree stems > 2m tall. Seeds and seedlings are simulated on the basis of 50 cm x 50 cm cells. The current version can simulate up to 9 ha on typical desktop computing environments in reasonable time periods; the simulation is written in C++, and runs under Windows 98/XP/Vista. Unlike SORTIE, our simulation explicitly models seed production, and disperses seeds in a spatially-explicit manner. Our model focuses on the detailed environmental conditions created within a windthrow area, as these affect seed survival, seed germination, and seedling survival. The 50 cm x 50 cm cells each have: location, seed bank density, herbaceous percent cover, and microsite type (e.g. intact soil, bare mineral soil, pit or mound, leaf or needle litter, or coarse woody debris). Light is modeled for each cell and for each tree as the amount of direct-beam radiation, which is decreased by taller neighboring individuals; seed germination and tree growth as explicit functions of light availability. Wind disturbance occurs in a discrete, circular area of specified size, located in the center of the simulated stand. Severity of damage within the disturbed area can be specified by the user. In the disturbed area, the fate (undamaged, snapped, uprooted) of individual trees is stochastically determined from logistic relationships based on tree size and species. Regeneration can be modeled for up to 50 yr following the disturbance, and is modeled on an annual time step.

Our simulation allows a great deal of user flexibility in choosing the size of the area disturbed, windthrow severity, cover of herbaceous vegetation, seed bank characteristics, intensity of browsing, and whether the windthrow area is salvaged or not. This model allows structure and composition scenarios to be simulated for a variety of types of wind disturbance, with or without salvaging, with or without browsing, for up to 50 years after the disturbance.

Keywords: windthrow modeling, computer simulation, regeneration, salvage

Tree Drawings: Recording Wind Conditions

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The following describes a devised method of capturing "drawings" of the movement of branches under a wide variety of airflow circumstances. This graphic model is produced by attaching a pen to the lower branch of a tree and, on a tripod, carefully positioning a drawing surface to best record the resulting marks. Reacting to the wind, branch movement produces patterns that are characteristic of the type of tree, position of branch, leaf shape, wind velocity and direction, surrounding canopy profile, turbulence, terrain, temperature, etc. (Tree identification was taught to me by my father, who studied forestry at Lewis and Clark. Wind analysis and prediction has been self-taught, including *Wind and Trees,* Ed. Coutts and Grace from the 1993 conference.) Early experiments in 1999 used a convenient pear tree at the Dia Center for the Arts on eastern Long Island, combining art and science to make visual models of usually invisible forces, like the winds' effect on trees. Some of the earlier work was recently selected to be in the upcoming Columbia Journal of Literature and the Arts (issue 44) because it is a form of documentation that marries the sensitivity of art to the rigor of science. Currently, native trees are preferred and locations are chosen based on prevalence of extreme wind conditions (Paloverde in the Banning Pass, CA; Kiawe at Makapu, HI; a grove of Aspen in southeasten Wyoming; dwarfed (krummholtz) Black Spruce, Mt. Washinton, NH.) As a general guide I use the NREL wind resource maps. For local conditions I consult NOAA and raw sensor data from the NWS. Once at a location, many hours are spent in learning the winds' relationship to the specific terrain, comparing the predicted winds with on site measurements using an anemometer (Kestrel 4000), documenting and photographing the winds' effect on tree growth, choosing a particularly wind affected tree and a finally a branch whose movements are a good representative of that species' characteristic gestures. The duration of a drawing is anywhere from ½ hour to 5 hours. The title of each drawing includes all of the conditions (eg. *Knobcone Pine – 1 hr – winds from the north west 15-28 mph gusting to 31 – Liebre Mountain, above the "Old Ridge Road", elevation 4500'. Southern California. Sat. May 27, 2006*).

Mechanical models of trees and clumps wind stability

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There was introduced a model for estimation of the wind stability of the single trees. This model allows analyzing of the behavior of a tree, which is affected by wind forces, either as the stability of an elastic rod with an elastic attachment, or as the stability of a rigid column on an elastic sub-grade. These two approaches present two limiting cases of tree bending under the impact of horizontal directed wind force.

The problem of estimating of the whole stand resistance to wind impact cannot be reduced to estimating the wind resistance of a single tree. The wind stability of a stand as a whole is more complex than the sum of factors that are affecting the wind stability of the single trees. The tree crowns touch each other and overlap when the stand is dense enough. Such "cohesive" trees possess high wind resistance.

The wind resistance of clumps of *Pinus sibirica* L. and *Abies sibirica* L. was considered in the model. Such clumps are found naturally in the mountain forests of Sayan (South of Siberia). The model demonstrates that the cooperative effects between trees contribute to the wind resistance of the clump as a whole.

Field studies of the wind impact on trees were conducted in the mountain forests of Sayan where spatial coordinates of all trees at the probe areas were determined. These data were used to test and verify the single tree and clump wind stability models.

Key words: high winds, clump, wind resistance, wind stability.

Distance-limited topex map for British Columbia

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Windthrow is an important natural disturbance of forests in British Columbia, as well as resulting in losses of timber and damage to utilities and other values. Assessing windthrow hazard is thus important to understanding disturbance ecology, as well as for forest management and infastructure planning. Topographic exposure to wind was identified as an important factor influencing windthrow in the United Kingdom, which resulted in the development of a topex, or index of topographic exposure in the UK. A modification of classical topex, the distance-limited-topex enables automated calculation using digital elevation data. Topex is used in the ForestGALES mechanistic windthrow prediction model to predict local windinesss. Distance-limited-topex is a key predictor in empirical windthrow prediction models for cutblock edges developed by the Windthrow Research Group at the University of British Columbia, for locations throughout BC.

In order to apply mechanistic or empirical models across BC, it is necessary to produce full grid coverage for the province. In this project, we determined topex values using a 1:20 000 (30 x 30 m cell size) digital elevation model (DEM) for the province. This was done by subdividing the provincial DEM into 300 tiles to enable processing of the distance limited topex with a script developed by the Windthrow Research Group at the University of British Columbia on a desktop computer, allowing for a buffer at the edge of the tile. Processing took approximately 7 minutes per tile; the topex out was reassembled into a provincial scale distance limited topex grid in ArcGIS. One proposed application of this provincial topex map will be for the estimation of stand susceptibility to spruce bark beetle.

Keywords: windthrow hazard mapping, topographic exposure, topex

Ice-storm and forest restoration in Republic of Moldova

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In accordance with data of Agency "Hidrometeo", on 21-25 November 2000 year, air zone with low atmospheric pressure on the South-East of cyclone's periphery, which moved from Great Britain towards Norwegian Sea changed on the end of period air zone with high pressure, which was spread from the East and bond with cold anticyclone. Weather without important precipitations, but with fog and +5+10°C during the night and +6+12 °C during the day was changed on 25 November by the weather with rains (0,0-3 mm during the 12 hours) and fog. The temperature of the air in the frontal zone was in the limits from –1+7 °C during the night and +1+14 °C during the day

At 26-28 November over territory of Moldova was recorded displacement of height currents that brought to intensification of frontal zone. In the layer near to the ground in the Southwest periphery of the cold anticyclone from the East moved cold air with negative temperatures, but from the West moved warmth and moist air. As a result of this conditions in northern and central districts of Moldova was formed strong ice storm. Its maximum precipitation touched 28-33 mm that brought to the deterioration of line power lines, forests, and orchards.

In Moldova were deposited precipitations in the shape of rain, rain with ice; rain with snow, at 27 November was recorded strong precipitations with quantity until 16-44 mm. At 27 November was recorded isolated Eastern and Southeastern wind intensification until 15-24 m/s. The minimum air temperature oscillated in the limits from –2°C until +10°C, and maximum – from –2°C until +11°C.

The ice storm from 26-28 November 2000 has severely affected national forest fund in the districts Orhei, Soroca, Edinet, Lapusna, Ungheni and Balti. The area of affected forests constitutes 51 thousand hectares. Material damages had constituted 135,5 mln.lei (11 mln. $). According to the estimations of economic damages caused to forestry sector constitute: from non-harvesting of high quality wooden mass of exploitable age; from the partial damage of trees and essential reduction of assortment varieties of wooden mass; un-compensated costs for cleaning of damaged areas; from reduction of non-wood forests products of affected forests during 10 years.

As a result of big economical and biodiversity damages both production and scientific institutions are in a dilemma, how to save remaining stand and how to straight the damaged forests into right directions. The problem is how much is necessary to cut or sometimes could be touched this forest not at all? Settlement of this problem separated practitioners and researcher in two groups. First, the bigger one is to cut the most part of forest because to save the wood from disease and pest and after to plant new forest. Second, the smallest one is to maintain the damaged forest for seedling and wildlife protection because of dry climate and then to apply successive cutting in dependence of seedling growing.

A Simple Linear Model for Estimating Energy Losses from Crown Collisions

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Crown collisions are thought to play a major role in the transfer of kinetic energy among trees within the forest canopy. Recent observations in a lodgepole pine forest suggest that the sway frequencies of individual trees within a forest stand can deviate from their fundamental frequencies as wind speed rises because of energy transfer via crown collisions. In this research, a linear model of tree motion has been used to examine what factors may be responsible for the observed shifts in sway frequency and to determine whether the observed frequency shifts can be used to estimate energy changes associated with crown collisions.