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Effect of birch and spruce mixture on wind-stability of trees

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Abstract. Establishment of mixed stands, especially mixture between confider and broadleaved tree species, is often recommended as a measure to adapt to climate change. However, the actual overyielding or adaptation effect depends on the species involved, type of mixture, management regime and impacting factor. Spruce-birch mixture is very common in hemiboreal forests, usually appearing in planed spruce stands with additional birch regeneration or ingrowth (advance regeneration) of spruce in naturally regenerated birch stands. The aim of the study was to assess wind resistance differences between Norway spruce and silver birch growing in pure and mixed stands. Static tree pulling was carried out in middle-age stands to obtain basal bending moments (to characterize tree wind stability) and plot inventory combined with evaluation of areal (drone) images for neighbourhood analysis of tree canopies. Basal bending moments were dependent on tree size for both species and higher for birch than for spruce. However, no significant influence of tree species, affecting primary or secondary failure, were detected. Establishment of birch-spruce singe-tree mixture can't be viewed as a measure to reduce wind damage risk.

Key words: mechanical stability, mixed stands, wind resistance, windthrow.

INTRODUCTION

Mixed forest stands are characterized by the coexistence of more than one tree species growing alongside in the stand; such stands represent more than two thirds (ca. 70%) of the total forest area in Europe (FAO, 2016). Lately, mixed stands has been recommended as a preferable option compared to monocultures due to their potential to provide an acceptable combination of timber production, ecological functions, biodiversity and forest ecosystem services (Jonsson et al., 2019). In addition, mixed stands may be more resilient and resistant to biotic and abiotic disturbances caused by climate change (Pretzsch et al., 2013).

Despite the available information of recommended species admixture in the scientific literature (Pretzsch et al., 2010; Felton et al., 2016; Engel et al., 2020; Ruiz-Peinado et al., 2021) none of species recommendations for mixed stands is universal and applicable to every stand. Before establishment of such stands a thoughtful evaluation of species admixture and combination is required and most importantly against which particular damage type we hope to improve the resilience. Currently, for many regions, it is still not determined how well individual mixed-species alternatives can balance the trade-offs between available resources and adaptive capacities to different disturbances (Felton et al., 2016). Moreover, mixed stand resilience is affected by several other factors, such as spatial distribution (situated in groups or evenly), differences between tree dimensions (height and diameter at breast height) and age of tree species (Donis et al., 2018).

Wind is one of the most significant natural disturbances and it is projected that the frequency and intensity of extreme weather events will increase in the future (IPCC, 2019). Furthermore, with increasing climate change, northern forests are expected to be even more susceptible to wind impact during summer thunderstorms and extra-tropical cyclones (Suvanto et al., 2016). Projected changes can cause notable economic loss and reduce the value of other ecosystem services. The susceptibility of forest stand to wind damage is controlled by wind climate (wind speed, duration, gustiness), forest structure, stand characteristics (tree species, tree height, diameter at breast height, crown and rooting characteristics, stand density) and soil condition (Peltola et al., 2010). Therefore, it is important to assess the influence of mixed stands on wind damage probability compared to pure stands. Analysed National Forest Inventory data from windstorm "Gudrun" that severely affected the territory of Latvia in January 2005 revealed that overall level of damage was similar between mixed and pure stands, except when admixture consisted of Norway spruce (*Picea abies* L. Karst.) - in such stands susceptibility to wind damage was increased (Donis et al., 2018). The probability of wind damage to Silver birch (*Betula pendula* Roth.) was significantly affected by stand age, basal area, soil type and dominant tree species in the stand. Moreover, birch had significantly lower wind damage probability in stands dominated by Scots pine (*Pinus sylvestris* L.) compared to stands dominated by other tree species (the species are ranked in increasing order of probability): grey alder (*Alnus incana*) < birch (reference level) < spruce < aspen (*Populus tremula*) < black alder (*Alnus glutinosa*) (unpublished).

Some authors have found that wind damage probability can be reduced by establishing mixed stands (Dhôte, 2005; Valinger and Fridman, 2011), and the natural relation between birch and spruce makes it possible to combine these tree species in a mixed stand with the probability of producing acceptable ecological combination and timber production (Johansson, 2003). Therefore, it is important to evaluate the complementarity of birch and spruce in mixed stands in order to reduce wind damage probability in the stand, as those are one of the economically most important and common tree species in Latvia's forestry (Ministry of Agriculture, 2021). The aim of the study was to assess wind resistance differences between Norway spruce and silver birch growing in pure and mixed forest stands.

MATERIALS AND METHODS

Study area and design

The study was conducted in five stands in central part of Latvia (Fig. MAP), of which two stands were dominated by silver birch, other two dominated by Norway spruce and one mixed stand. Altogether, 79 trees were selected within five stands growing on mineral soil. Each of selected tree was used as the centre of circular sample plots (500 m2, R=12,62m). In every sample plot for each tree the height (H), diameter at breast height (DBH) and canopy starting height was measured. The canopy borders for each tree within sample plots were extracted as contour from digital surface height model (DSM). In order to analyse the tree canopy spatial distribution and configuration, the lowest and highest contours of bent tree were used as base heights. Extracted contours were converted to polygons and within each of sample plot, they were grouped into three groups: open area, bent trees and neighbouring tree. In addition, we calculated the length of coincident edges between bent tree and neighbouring tree or open area which was calculated for tree canopies at two heights (the lowest canopy height and the highest canopy height). The spatial diversity and configuration within each sample plot were calculated in ArcGIS 10.5 software. The relationships between selected tree (bent tree) and its neighbouring trees were assessed by analysis of neighbourhoods (e.g. the area analysis, edge analysis and diversity analysis) utilized with ArcGIS (10.x) extension vLate (2.0 beta) (Tiede, 2012).

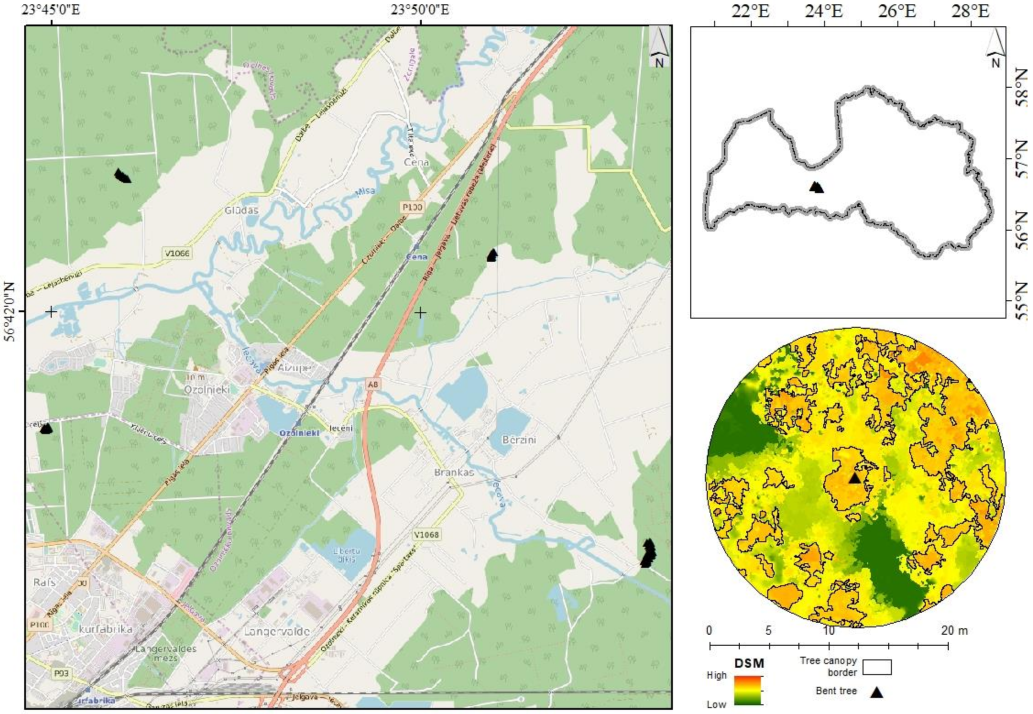

Figure MAP. The location of bent trees in central part of Latvia. The example of neighbourhood analysis (bottom right) where tree canopies were extracted as contours from digital surface model.

In statistical software R (version 4.0.0) using the package lme4 (R Core Team, 2020), the linear mixed-effect model was computed to test the effect of variables, such as mean canopy area, mean canopy perimeter from DSM, Shannon`s Diversity Index, Shannon`s Evenness Index and dominance on the bending moment of primary and secondary failure. To deal with pseudo-replication and to account for possible correlation among trees from the same stand, the stand was treated as a random factor (Bates et al., 2015). We tested different combinations of factors stepwise in the model by minimizing Akaike`s Information Criterion (Burnham and Anderson, 1998) to determine the best model. The Kenward-Roger approximation was used to estimate the degrees of freedom, and the 95% confidence interval was recorded.

RESULTS AND DISCUSSION

Based on our model of the Shannon`s Evenness index, the perimeter of canopy for bent tree and neighbouring trees showed the best fit for primary failure, while the Shannon`s Evenness index, bent tree canopy area and the length of canopies for neighbouring trees. In mixed stands the mean Shannon`s Evenness Index was 0.01±0.001 and 0.24±0.083 for spruce and birch, respectively, while in pure stands the index was 0.23±0.06 and 0.31±0.063 for spruce and birch, respectively (Fig. 2.).

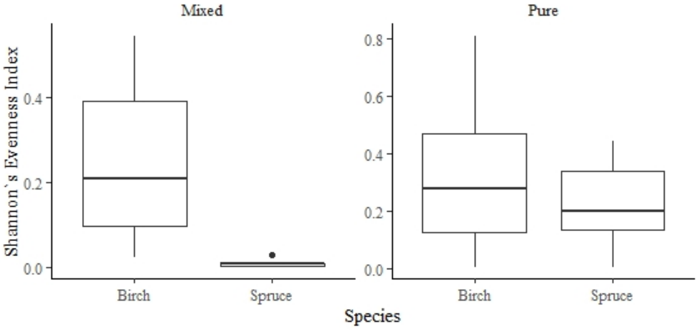

Figure 2. The Shannon`s Evenness indices as a measure of the canopy diversity

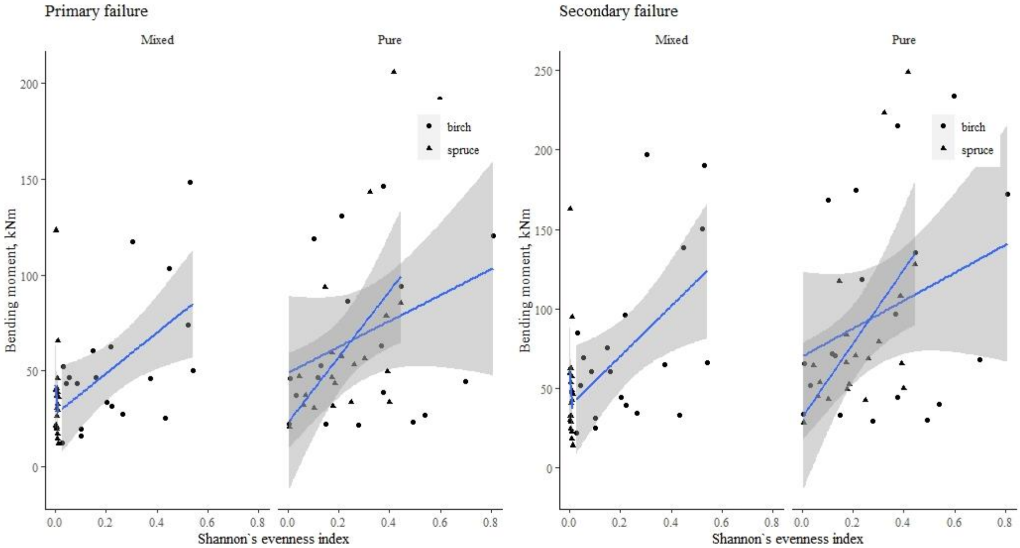

Figure 3. The relationships between bending moment between different species and dominate species

There were strong relationship between canopy diversity and the bending moment for both failure types (primary and secondary failures). The higher diversity of the canopies in the neighbourhood significantly increased the load to reach primary and secondary failure (Fig.3.).

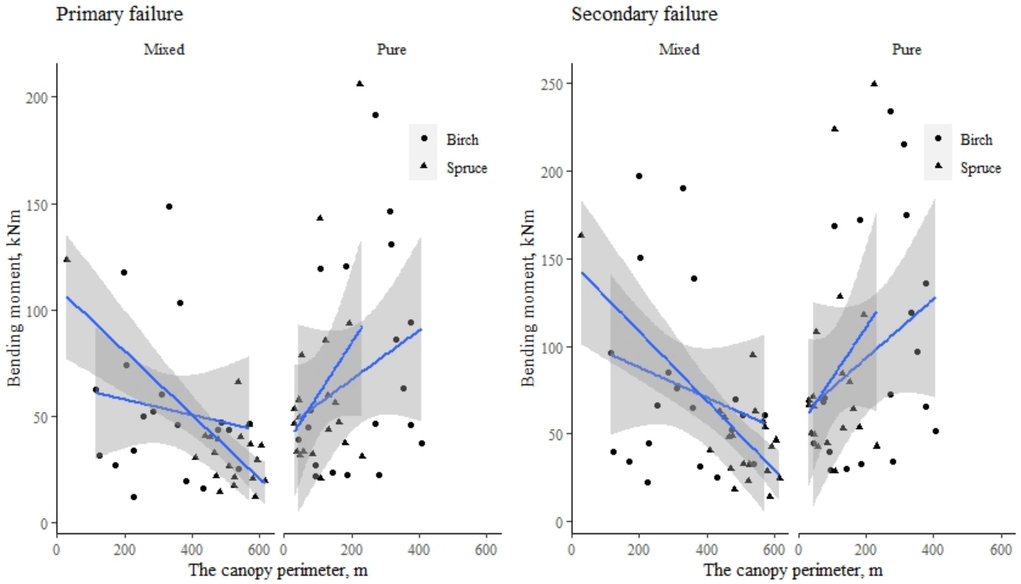

Figure 4. The relationship between total length of all neighbouring trees canopies perimeter and the bending moment

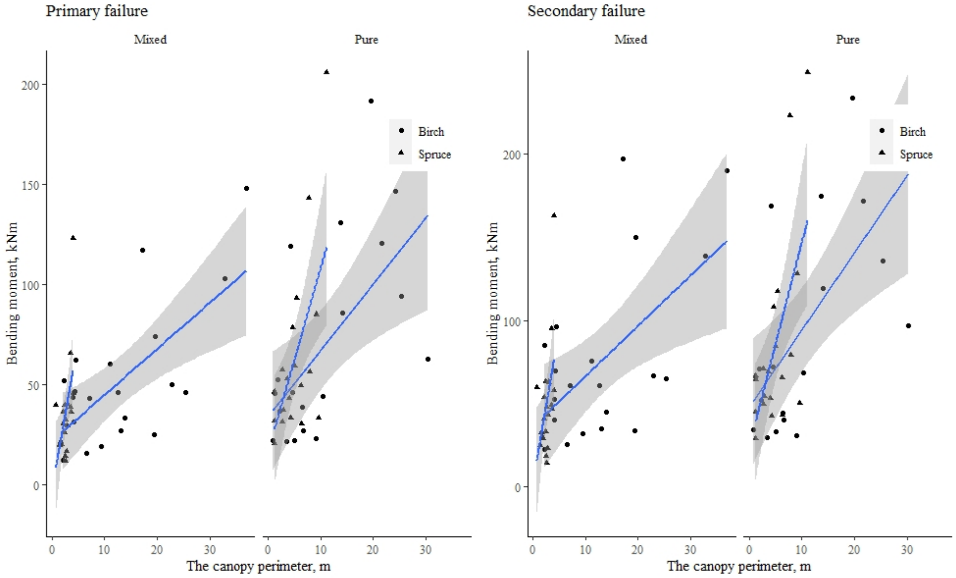

Figure 5. The relationship between total length of bent tree canopy perimeter and the bending moment

We also found that the total length of all neighbouring tree canopy perimeter within sample plots and the length of bent tree canopy perimeter has affected the trees bending moment. However, it differed between mixed and pure stands, accordingly, in mixed stands the load required to reach primary failure or secondary failure decreased for plots with higher total length of neighbouring tree canopy perimeter, in controversially, our results suggested that in pure stands, to reach tree failure the load increased with increased perimeter of all neighbouring trees (Fig.4.). In addition, the canopy perimeter of bent tree had direct impact on the trees resilience, obviously, the load to reach tree failure increased significantly (*$p<0.05$*) with increasing length of canopy perimeter for bent trees (Fig.5.).

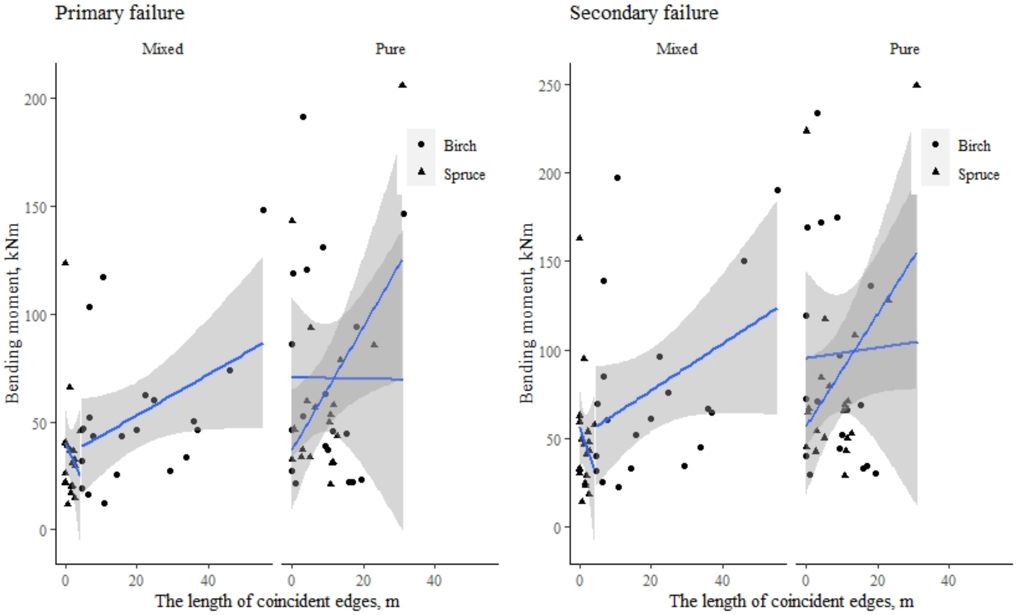

Figure 6. The relationship of tree bending moment between the length of coincident edges of lowest canopies heights between bent tree and neighbouring tree

The coincident edges between bent trees and neighbouring trees at lowest canopy height differed among mixed and pure stands and was 19.9±7.12 m and 1.2±0.56 m within plots in mixed stands for birch and spruce, respectively, while within sample plots in pure stands the length of coincident edges was 9.3±4.13 m and 8.73±3.69 m for birch and spruce, respectively. Moreover, we found that with increasing edge length of coincident neighbours also increased the resilience of bent trees, namely, there was significant ($p<0.001$) relationship between bending moment and the length of the coincident edges at lowest canopies height, where the load to reach primary failure or secondary failure increased along with increasing length of shared canopies edge.

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