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Brief Report

Cervid Bark-Stripping Is an Explicit Amplifier of Storm Legacy Effects in Norway Spruce (*Picea abies* (L.) Karst.) Stands

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Abstract: The interactions between wind damage and biotic agents, such as root-rot and cervids (bark-stripping), amplify the effects of storms on forests in Europe and Norway spruce (*Picea abies* (L.) Karst.) stands, in the Eastern Baltic region in particular. Due to uneven manageability of the biotic agents, the information about their effects on susceptibility to wind damage can aid the prioritization of management for sustaining spruce stands. This study compared the effect of root-rot and bark-stripping on the mechanical stability of Norway spruce via mixed covariance analysis of basal bending moments, based on static tree-pulling test data of 87 trees from five stands in Latvia. Bark-stripping caused a significantly stronger reduction in resistance against the intrinsic wood damages (primary failure) compared to root-rot, while showing a similar effect on resistance to fatal (secondary) failure. This suggests that bark-stripping damage increases the susceptibility of spruce to storm legacy effects, and, hence, is a higher priority risk factor in Norway spruce stands under the climate-smart management approach.

Keywords: static tree-pulling test; bark-stripping; root-rot; wind damage; climate-smart forestry

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1. Introduction

The negative synergic legacy effects of the increasing intensity of storms and biotic disturbances [1] are the main drivers of the northwards retreat of Norway spruce (*Picea abies* (L.) Karst.), which is explicit in the Eastern Baltic region [2]. Although bark beetles are the "hangman" of spruce [3,4], other biotic agents, such as root-rot and cervids (bark-stripping), which are common in the region [5–9], increase the susceptibility of trees to additional stress [10–12]. The latter two can affect the mechanical stability of trees, enhancing effects of storms and thus forming a negative feedback loop [13]. Yet their impacts might differ due to damage to distinct parts of the tree [12,14]. Accordingly, information about the effects of root-rot and bark-stripping on tree mechanical stability can aid prioritization and targeting of management for sustaining spruce stands. The aim of the study was to compare the effects of root-rot and bark-stripping on mechanical stability of Norway spruce by reanalyzing existing static tree-pulling test data [15,16]. Considering uprooting as the main type of fatal failure of spruce within the region, root-rot, which damages roots directly, was hypothesized to cause a greater reduction in the mechanical stability of trees than bark-stripping.

2. Materials and Methods

The comparison of the effects of bark-stripping and root-rot on the mechanical stability of Norway spruce was based on reanalysis of data from previous studies, which were conducted in Latvia (Eastern Baltic region) [15,16]. In total, 87 trees from five stands affected either by root-rot or bark-stripping were analyzed. The presence of fungal pathogens was tested in the laboratory prior to the pulling test. The effect of bark-stripping was assessed for trees with 7–9-year-old wounds located on stems at the height of 80–150 cm; wound area ranged from 603 to 2375 cm^2. The studied trees were growing under comparable site conditions (mesotrophic mineral or drained deep peat soils on flat lowland topography) and had similar dimensions (stem diameter at breast height of 16–46 cm, height of 15–31 m).

The data were collected by uniform methodology in terms of selection of stands and sample trees (stratified selection), as well as the static tree-pulling test [15,16]. In brief, maturing (40–80 years), evenly distributed canopy trees of spruce-dominated stands were sampled in a destructive manner under static pulling to assess the loading resistance at the stem base at both primary and secondary failures [15,16]. During the bending, the resistance (basal bending moment) and stem curvature increased proportionally until structural changes (wood compression) occurred. This point signified the primary failure, after which the proportionality between stem curvature and basal bending moment was shifted. Secondary failure was the maximum loading resistance as a tree collapsed [17,18].

The effect of bark-stripping and root-rot on the basal bending moment of the stem, at both primary and secondary failures, was assessed by linear mixed-effects models (analysis of covariance), including a proxy for tree size, as follows:

$$y_{ijk} = vol_{ij} + st_k + vol_{ij} \times st_k + (stand_j) + \varepsilon_{ij}, \tag{1}$$

where vol_{ij} is the stemwood volume used as the covariate of tree size and foliage biomass [19], st_k is the fixed effect of damage type, and $vol_{ij} \times st_k$ is the interaction between tree size and damage type. Considering the differing number of sampled trees, stand was included as the random effect ($stand_j$). The significance of the fixed effects was estimated by Wald's χ^2 test. Data analysis was conducted in R (version 4.2.1, Vienna, Austria) [20], using package "lme4" [21].

3. Results and Discussion

Wind impact to trees is commonly thought to consist of uprooting or stem breakage; however, first intrinsic damages, which are not visually evident, occur long before that [17,18]. These damages are the primary failure—a rupture of wood, which impairs tree hydraulics, causes physiological drought [17,18] and thus increases susceptibility to storm legacy effects (e.g., bark-beetles) [1]. The legacy effects, in turn, reduce the wind resistance of trees, forming a negative feedback loop [13]. Although the biotic agents reduce the mechanical stability of middle-aged Norway spruce [15,16,22], bark-stripping caused a significantly stronger reduction in resistance against the primary failure compared to root-rot. This was shown by a significantly ($p < 0.01$) less steep regression slope between the basal bending moment of the stem and stemwood volume compared to root-rot (Figure 1; Table 1), implying increased susceptibility to post-storm legacy effects [23,24]. Such a stronger effect of bark-stripping could be related to acute stresses caused by the injury, as well as interruption of conductive tissues [25] accompanied by infestation by pathogens [10,12]. In contrast, root-rot is a chronical disease of spruce, to which trees attempt to adapt [26].

The overwhelming uprooting of spruce during the pulling tests [15,16], as well as storms [27], indicate that the fatal (secondary) failure of spruce mostly occurs in roots. The lack of differences in resistance to secondary failure, as indicated by the similar ($p > 0.05$) relationship between the basal bending moment and stemwood volume (Figure 1; Table 1), implied equal probability to survive wind events irrespective of biotic agent. Accordingly, the presence of the biotic agents does not directly cause weak spots in the collective stability of stands in short term [28]. This highlights the relevance of resistance of trees against the primary failure regarding the post-storm legacy effects on Norway spruce, which would likely lead to formation of weak spots in the collective stability of stands by secondary agents in the long term, intensifying storm legacy effects [28]. However, it must be admitted that the extension of root-rot within the stem, which can affect the biomechanics [15], was not controlled, leaving a research gap. In addition, the effect of time since bark-stripping, which can be associated with physiological stress response in trees and pathogen infestation [10], still appears to be topical.

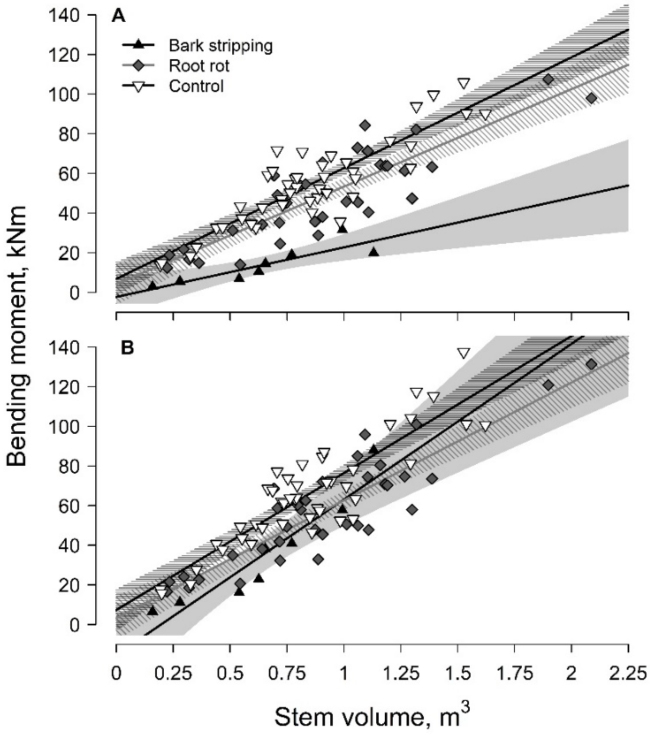

Figure 1. Estimated effects of bark-stripping and root-rot on the basal bending moment of Norway spruce at primary (**A**) and secondary failures (**B**).

Table 1. Strength (Wald's χ^2), significance (*p*-value), random effect of stand, and performance (R^2) of the linear mixed-effects models characterizing the effect of biotic disturbances on the basal bending moment of Norway spruce at the primary and secondary failures, under static loading. σ^2—total variance of response; τ_{00}—variance related to random effects (site); ICC—intraclass correlation coefficient.

	Primary Failure		**Secondary Failure**	
Predictors (χ^2)	χ^2	***p*-Value**	χ^2	***p*-Value**
(Intercept)	0.14	0.71	4.29	<0.05
V_{stem}	5.59	<0.05	35.13	<0.001
Damage type	0.47	0.79	5.08	0.08
V_{stem} by damage type	10.48	<0.05	3.76	0.15
Random Effects				
σ^2	84.2		132.18	
τ_{00}	38.33 $_{site}$		36.24 $_{site}$	
ICC	0.31		0.22	
n_{stand}	5 $_{stands}$		5 $_{stands}$	
Observations	87		87	
Marginal R^2	0.82		0.82	
Conditional R^2	0.88		0.86	

Under intensifying effects of storms [29–32], the relevance of biotic agents, as components of negative feedbacks reducing sustainability of stands, increases, implying the necessity of agile prioritization of management [33]. Targeted reduction in browsing damage, which is more controllable compared to pest outbreaks and fungal diseases [34,35], appears as a priority climate-smart measure, aiding the reduction in the storm legacy effects in Norway spruce stands.

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