THÜNEN

Project *brief*

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Storm damage in forests: Modeling the windthrow risk for Germany with ForestGALES

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- **Improved predictive capacity of storm damage probabilities through statistical calibration.**
- **Regional parametrizations for European beech, Norway spruce and Douglas fir.**
- **Increase in overall model accuracy by 2% (European beech) to 6% (Norway spruce, Douglas fir).**

Background and aims

In the past, severe winter storms, such as Lothar (1999) and Friederike (2018), caused severe damage to forests throughout Europe. From 1950 to 2000, 53% of all harvested timber was related to storm damages resulting in severe ecological and economical loss (Patacca et al., 2023). Severe winter storms already cause large amounts of damage to managed forests today and for the Central European region, an increase in storm severity is projected to occur under climate change. In addition, secondary disturbances, such as bark beetle infestations, compound disturbances and disturbance interactions can further affect forest ecosystems. However, storm events cannot be prevented and it is not possible to predict their occurrence (Mölter et al., 2016). One way to identify areas which are at a high risk of damage, is to use different modeling approaches. Common types of models include statistical models, as well as hybrid-mechanistic models. With which processes that are connected to the damage generation can be researched in more detail. The model used in this study is called ForestGALES (Gardiner et al., 2008) and it is such a hybrid-mechanistic model, which was first developed for forests in the UK. One important goal variable of the model is the critical wind speed (CWS), which is the wind speed at which damage by uprooting or stem breakage occurs. By calculating this CWS and estimating its occurrence probability in relation to the local wind field, models such as ForestGALES can be used as a supporting tool for the management of forest stands in regards to storm damage reduction.

In the WINMOL project we adjusted the ForestGALES model for German forest stands and tested whether this adjustment increased the model's predicitve capacity (Stadelmann et al., 2025).

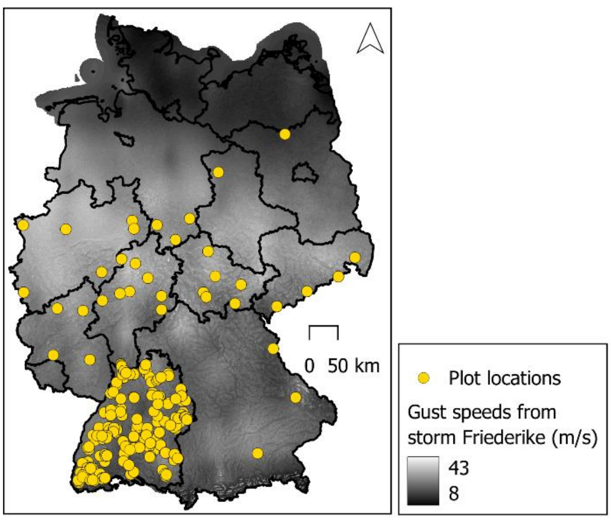

Figure 1: Plot locations of individual tree plots (yellow markers). The gust speeds (m/s) of the storm Friederike are shown in the background (source: GeWiSA; Jung and Schindler 2019).

Approach

For the model calibration we used a large dataset of 123369 single trees on 1259 plots (Fig. 1; yellow markers). The data is sourced from long-term growth and yield plots from the state of Baden-Wuerttemberg (southwest Germany) (Forest Research Institute Baden- Wuerttemberg, Germany (department Forest Growth)) and from the intensive forest monitoring network (Level II; recorded according to ICP Forests protocols) and it includes information on the single trees and stands, as well as on potential storm damage. We focused our analysis on the tree species Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*) and Douglas fir (*Pseudotsuga menziesii*), because we had sufficient data on tree and stand characteristics for these species. In addition to the tree data, we extracted information on the soil type from the soil map of Germany (BUEK200) and topographical information from the digital elevation model (© GeoBasis DE / BKG 2024) at each plot location (Fig. 1, yellow markers).

To calculate the CWS we use the "TMC method", which is the method implemented in ForestGALES that calculates the storm damage risk for single trees within a stand. In a second step we compared these calculated CWS to historical wind data (GeWiSA; Jung und Schindler 2019) and calculated the damage probabilities.

We created a regionalization of the model for German forests by applying a statistical calibration approach, where single internal model parameters were iteratively changed and each iteration of model parameters was then compared to the reference data. The final parameter combination is the one where the modeled storm damage matched the reference data the best (Stadelmann et al., 2025).

Table 1: Comparison of the FG classification results for European beech, Douglas fir and Norway spruce for one optimization approach (adjusted) in comparison to the FG default species-specific parameters (default Results are shown for the validation subset. ACC: Overall accuracy (ratio of correct predictions over all predictions), AUC: area under the receiver-operator-characteristics curve, MCC: Matthew's correlation coefficient. Fields with the better value for each model goodness evaluation are indicated by a green background color.

		ACC	AUC	MCC
European beech	default	0.65	0.69	0.41
	adjusted	0.67	0.74	0.43
Douglas fir	default	0.54	0.58	0.11
	adjusted	0.60	0.65	0.33
Norway spruce	default	0.54	0.78	0.20
	adjusted	0.60	0.78	0.29

Results

Through the automatic statistical calibration, we were able to improve model performance for the "TMC method" for all three tree species (Tab. 1). For the performance evaluation we focused on the improvement of the Matthew's Correlation Coefficient (MCC), which is a measure of model goodness where all fields of the confusion matrix are included in the evaluation. This means that in the MCC, correct and false classifications of both, damaged and undamaged trees, are included. For all three tree species, the majority of the selected measures of model goodness were improved (Tab. 1, cells highlighted in green).

We saw the largest improvements for Douglas fir. For this tree species, the model underestimates the damage probability to storm damage less often, while however, classifying undamaged trees as damaged slightly more often.

For European beech and Norway spruce, the default model parametrization tends to overestimate the damage probability. We were able to reduce that in our adjusted model version, but the rate at which damaged trees are modeled as damaged has also decreased slightly.

More detailed results and the final adjusted species-specific parameter values can be found in Stadelmann et al. (2025).

Conclusion

Optimizing the region- and species-specific parameters of ForestGALES can improve the model's predictive capacity. With improvements to the model predictions, forests and stands at risk of damage can be identified and timely management strategies can be employed to reduce potential damage.

We believe that further research into risk assessment of storm disturbances is essential, especially under the influence of climate change and when considering secondary disturbances. Some future research avenues could include:

- Utilizing lidar data to generate single-tree input data for larger forested areas.
- Evaluating the ForestGALES model for mixed species stands.
- Analyzing the influence of different soil types and soil moisture contents, as well as of water saturated soils on the storm damage risk.
- Analyzing the influence of forest edges and forest gaps on the storm damage risk.
- Validating the species-specific parameters generated through the automatic calibration with experimental data.

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Further Information

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Publications

Stadelmann et al., 2025. Improving the predictive capacity of the windthrow risk model ForestGALES with long-term monitoring data - A statistical calibration approach. Forest Ecol Manag 576:122389, DOI:10.1016/j.foreco.2024.122389.

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