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The effect of landscape composition and configuration on forest disturbance risk under climate change

Juha Honkaniemi, Werner Rammer, and Rupert Seidl
University of Natural Resources and Life Sciences (BOKU), Institute of Silviculture, Vienna, Austria

Forested landscapes are strongly altered by human land use and forest management. In Central Europe, Norway spruce (*Picea abies*) has been favoured due to its high economic value and many areas naturally dominated by European beech (*Fagus sylvatica*) and other broadleaves have been replaced with Norway spruce stands. For instance, at the trailing edge of the Norway spruce distribution in Eastern Austria decades of planting Norway spruce increased the species share from a few percentages to nearly half. As a consequence, Norway spruce stands in the warm lowland climate are prone to natural disturbances mainly by wind and bark beetles. In addition, the projected climate change is predicted to increase the severity of these disturbances in the region. The aim of this study is to analyse the effect of landscape composition and configuration on the natural disturbance risk (i.e. wind and bark beetle) of Norway spruce at the trailing edge of its current distribution in a managed lowland landscape (200-750 m a.s.l) with a forested area of 6700 ha. We used a process-based model (iLand) to simulate combinations of spatial configuration (Norway spruce stands dispersed, clumped or aggregated in the landscape) and composition (10% to 50% Norway spruce share) under different climate change scenarios. The simulation results showed that both configuration and composition have an effect on Norway spruce disturbances. However, the impact of configuration was more significant under all climate change scenarios. Pure Norway spruce stands aggregated into one continuous area (aggregated) in the landscape was overall the most vulnerable configuration. For example, with a 30% Norway spruce share the mean annual timber volumes damaged by wind and bark beetles together under moderate climate change scenario (RCP 4.5) were 1.2, 1.3, and 2.3 m^3 ha^{-1} yr^{-1} for dispersed, clumped and aggregated configurations, respectively. While the damages were highest for the aggregated configuration, pure Norway spruce stands in small groups with a constant spacing (clumped configuration) had the least bark beetle disturbed timber demonstrating the potential to constrain bark beetle outbreaks with management choices. For the above example scenario, the mean annual timber volumes killed by bark beetles were 0.7, 0.5, and 1.2 m^3 ha^{-1} yr^{-1} for dispersed, clumped and aggregated configurations, respectively. Mixing Norway spruce with beech and other species (dispersed configuration) showed a mixed signal as it was the most resistance configuration against wind, but not against the bark beetle outbreaks. In the two configurations with pure Norway spruce stands (clumped and aggregated) the bark beetle outbreaks were driven by the availability of timber after storm events whereas in the dispersed configuration such pattern was not observed. In this study, the dispersed spatial configuration promoting mixed species stands was the most resistant against disturbances under climate change. Thus, altering the spatial configuration of tree species in a landscape could be a promising approach fostering ecosystem resilience and reducing the natural disturbance risks. The study results provide important insights for ecosystem managers to implement sustainable forest management under the changing climate.