

How restrictions of forest management affect landscape level wind damage risk

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Abstract

The current forest management seeks to reconsider timber harvesting while aim to improve forest diversity and halt biodiversity loss. Novel approaches as optimization of forest management, increasing proportion of set-aside forest stands, or novel management approaches such as continuous forest cover emerge. However, the stability of the forests and provision of ecosystem services will be challenged by climate change and appearance of more frequent climatic disruptions, such as windthrows. To understand how will the traditional (rotation forestry, RF) and novel forest managements techniques (continuous cover forest, CCF) alternate the risk of wind damages over the harvest intensity gradient, we combined the forest growth simulator, optimized forest management to calculate landscape levels wind damage risks for alternative forest futures given groups of management regimes (RF, CCF and combined: ALL) over the harvest intensity gradient over the landscape, or proportion of set-aside forests over 100 years. We found that higher harvest intensity in RF lowers wind risk, whereas the wind risk increased under CCF management. Overall, more intensive harvesting levels in RF produced more pulp, whereas production of log wood prevails under CCF. RF slightly increases the number of stands with open edge, and intensive harvesting might change species composition to favour Norway spruce which might further increases wind risk in the future. We conclude that forest managers should consider the target forest species composition to mitigate wind risk and to favorize production of log wood instead of pulp.

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Introduction

The current times are challenging to balance between forest productivity and biodiversity. Existence of biodiversity, mostly attached to existence of deadwood, is limited by harvesting levels. Intensive logging activities fragment forested landscapes. To balance between biodiversity and economic gain from timber, the proposition of set-aside forests within commercial forests emerges, and new forest management approaches are explored, such as continuous forest cover (Eyvindson 2020) and traditional harvesting regimes are becoming controversial or requested to ban (...). The increase of the set aside forests within the commercial forests, as well as development of the new management techniques affect landscape level structural diversity, timing of the thinning, presence or absence of the final cuts in rotation forestry or development of the larger trees within continuous cover forestry or in set-aside forestry. The fundamental is the careful landscape level planning of the management actions balancing between set-aside (unmanaged forests), intensive management and continuously present forest cover.

Optimal management scenarios fulfill the specific objectives of the society of forest owners to provide certain timber value, improve provision of timber and non-timber ecosystem services, or improve overall forest multifunctionality of the landscape. As such, optimization provides the combination of the specific forest management regimes on stand level. Although the optimization process does not necessarily involve the spatial configuration of the stands, it specifically assigns the particular regimes to individual stands and therefore allows to recreate alternative dynamics landscapes shaped by forest managements aggregated by optimal scenarios. As such, the spatial configuration of the management regimes allows to estimate the subsequent characteristics such as landscape level risk of wind damage.

The risk of the wind damage increases with current climate change and it creates the major risk to the stability of the forest production. Windthrows are unpredictable climatic disruption that shapes forest structure and composition, and if left unsalvaged could create opportunities for deadwood dependent species and support local biodiversity. From economical point of view, however, windthrows massively abrupt the continuity of the timber supply, lowers timber quality from log to pulp, increases the prices of unplanned salvage harvesting (REF). To lower the risk of wind risk damage, current suggestions include shortening the rotation period, promoting/avoiding the wind resistant vs. wind prone tree species, advocate for shortening of the minimal stand age (Latvia REF). This however poses further pressure on the multifunctional and multiple objective oriented landscapes, which will provide habitats for endangered species, support non-timber services and forest recreational use.

Traditional forest management regimes specialized in promoting timber revenues while minimizing costs. In Fennoscandia, over the decades, the traditional rotation forestry with multiple thinnings and final cuts that over just multiple

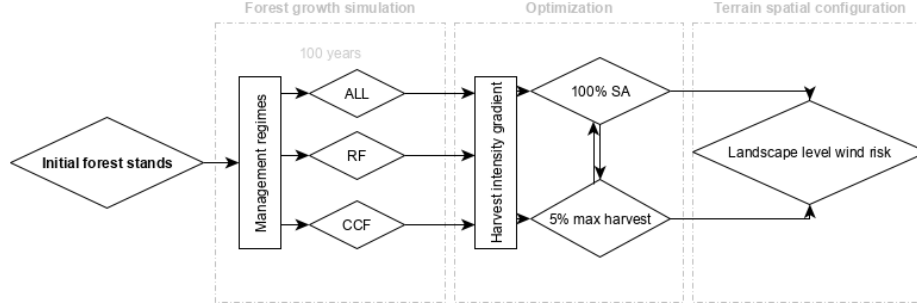


Figure 1: The study workflow from collecting initial stand conditions (2016) through forest simulation growth under various ranges of forest management, and construction of the harvesting intensity gradient using optimization to landscape level stand configurations.

decades (from 1950) homogenized stands structural diversity, homogenized landscapes and increased forest fragmentation. On the other hand, forest management supporting multifunctional landscapes, and promoting non-timber ecosystem services requires implementation of the diverse set of management regimes (Mönkkönen et al., 2014; Triviño et al., 2017). Furthermore, provision of the endangered species habitats and non-woody ecosystem services are provided on different scales where the planning scale should match or overcome the scale that provided ecosystem (Pohjanmies et al., 2019).

Here we explore how the restriction of forest management practices, along with the increasing level of harvest levels over the landscape affects landscape level damage of wind risk and how much timber value is put on risk under alternative regimes and extraction levels. Our study for the first time evaluates the landscape level wind risk combined with the forest growth simulator and long-term consequences of the applied forest management practices. Therefore, we first calculate the stand level wind risk over alternative landscapes and further explore the likely drivers of the wind risk levels. We investigated how restriction of forest management regimes combined with levels of intensity of timber extraction will affect landscape level wind risk.

Methods

Study area

Our study area represents a typical Finnish production forested landscape with relatively structurally homogenous forest stands. In total we used 1475 forest stands aggregated within a single watershed (number 14.534) in Central Finland, covering 2242 ha (Fig. 2). Initial stand conditions were collected as open source data from the Finnish Forest Centre (available on www.metsaan.fi) providing current stand conditions in 2016.

Our input datasets include initial stand conditions, simulation of the forest regimes using forest growth simulator, and stand configurations over the range of optimal landscape level forest management, varying from over the harvest

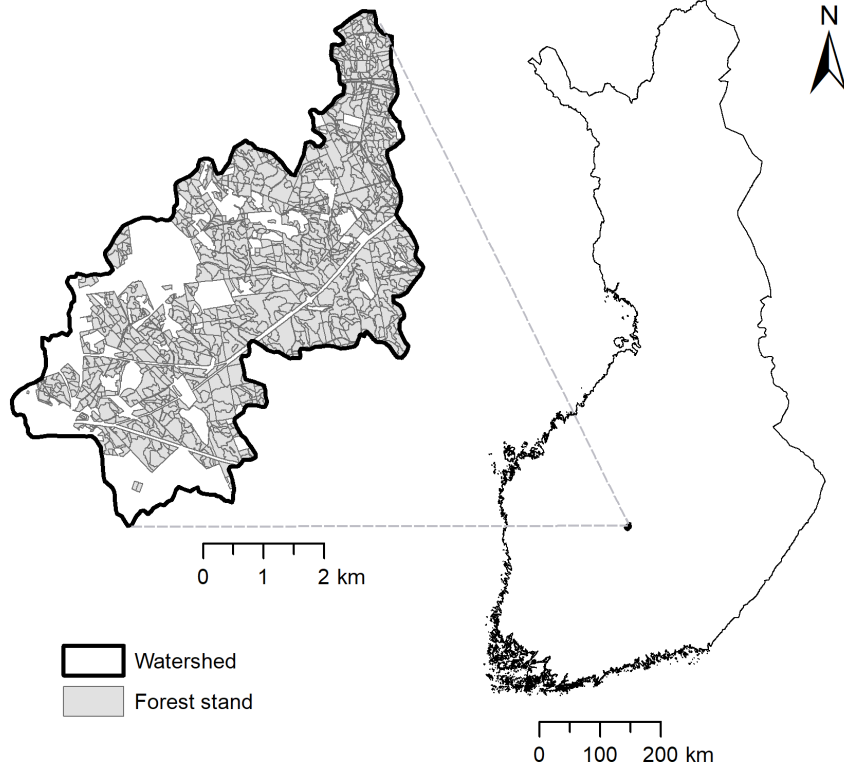


Figure 2: The study area located in Central Finland (watershed 14.534) comprising 1475 forest stands.

intensity is based on Eyvindson et al. (2021) study (Fig. 1), please refer for more details).

Forest stand development under different regimes

We simulated the development of the forests stands using SIMO forest growth simulator (Rasinmäki et al., 2009) over 100 years, separated into 20 5-year sequences. Each stand could be managed by up to 58 different management regimes (the total number of regimes per stands depended on the stand initial conditions), including 17 regimes for rotation forestry (RF), 40 variations of continuous cover forest (CCF) and one set aside (SA), where no management actions were taken. RF regimes different in in timing of final felling, optional thinning (present/absent), and increase in retained green trees after final cut (more details in Eyvindson et al., 2018). Basic CCF management follows rules from Äijälä et al. (2014). To increase the range of CCF managements, we varied two rules defining the timing of harvesting: site-specific basal area and timing of

the first thinning. The pre-defined site-specific basal area (m²/ha) requirement (16m²/ha for less fertile sites to 22m²/ha for fertile sites) prior to harvesting was modified by -3, ± 0 , +3, +6, and we delayed the timing of the first harvest in 5 year increments up to a delay of 45 years.

Optimization

The collection of the optimal management regimes explore the trade-offs between net present income (NPI) and forest multifunctionality. NPI represents economic value of the forests estimated by Metsähallitus (the Finnish governmental organization managing state owned forests) and higher NPI value presents higher timber extraction and oppose the proportion of the set-aside forest stands (i.e. without active harvesting). Optimization process over the NPI gradient was run using only RF, only CCF management types, or all possible managements (RF and CCF) included over the gradient of NPI values, from 0 (representing set-aside or no management in all stands) maximal amount of extracted timber (leaving up to 5% of SA stands). The optimization process resulted in creating of 63 alternative landscape development paths over 100 years period in 20 5-years time steps that different in applied management types (3) and levels of timber extraction (21), further referred as scenarios. Each optimized scenario represents a collection of management regimes applied uniquely over every stand. This setup allowed us to reconstruct the dynamics landscape development over time under combination of management regimes, and harvest extraction gradient.

Wind risk calculation

We have calculated the probability of wind damage based on Suvanto et al. (2019) binomial generalized linear model with logit-link function for each stand, under each scenario and at every time step. Suvanto et al. (2019) This model calculates the probability of the wind damage considering available relevant open-access datasets, specifically dominant tree species, dominant tree height, time since thinning, predicted levels on max wind speed (for next 10 years, this remain stable in this study), evaluated if stand has open edge, soil type, mineral soil depth, site fertility and temperature sum (refer to (Suvanto et al., 2019) for all details). As it is difficult to predict specific location of the occurrence of strong winds in the future, the model outputs show the relative differences between stands, damage can be only partial to the stand. To process the datasets, calculate damage probability models and visualize results we used R Development Core Team (2019).

Data processing

We calculated the probability of wind damage based on stand level for each stand, scenario and time intervals. First, we evaluated wind damage probability on stand level, which we averaged over the scenarios to allow comparison over the harvesting gradient, and application of RF, CCF and all possible management types. We hypothesized that RF would increase wind damage risk dues to increasing number of open edges while CCF would lower wind risk over the

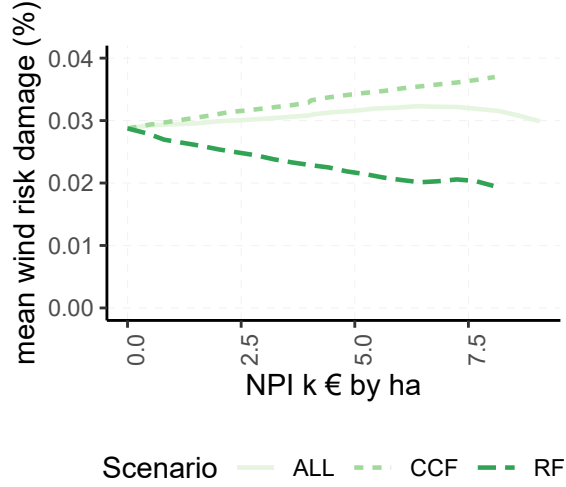


Figure 3: Mean wind risk damage for three types of management regimes over harvest intensity gradient

landscape. Further, we hypothesize that higher levels of timber extraction would increase wind risk. Lastly, we hypothesized that increasing amount of set-aside stands, over the landscape together with CCF management would increase wind damage risk due to larger present timber volume, and due to more frequent thinning activities. We investigated wind risk in terms of available timber volume, specifically saw and log timber volume. Lastly, we explored the trends of wind risk relevant to stands height, changes and species compositions.

Results

Landscape level wind risk under management restriction and harvest intensity scenarios

The set-aside landscape level management resulted at the same mean landscape level risk for all management regimes (Fig. 2). However, intensifying harvesting triggers different responses under groups of management regimes and intensification of the timber extraction. Sole use of the RF managements lowered the wind risk with increasing harvest intensity. On the other hand, both ALL and CCF scenarios increased the wind risk where CCF monotonically increased with increasing harvesting rates, while ALL regimes have slightly humpened curve shape, culminating around intensity of 7.5K by ha. The CCF increases monotonically while maximal harvesting increase the wind risk by 25% compared to completely set-aside stands.

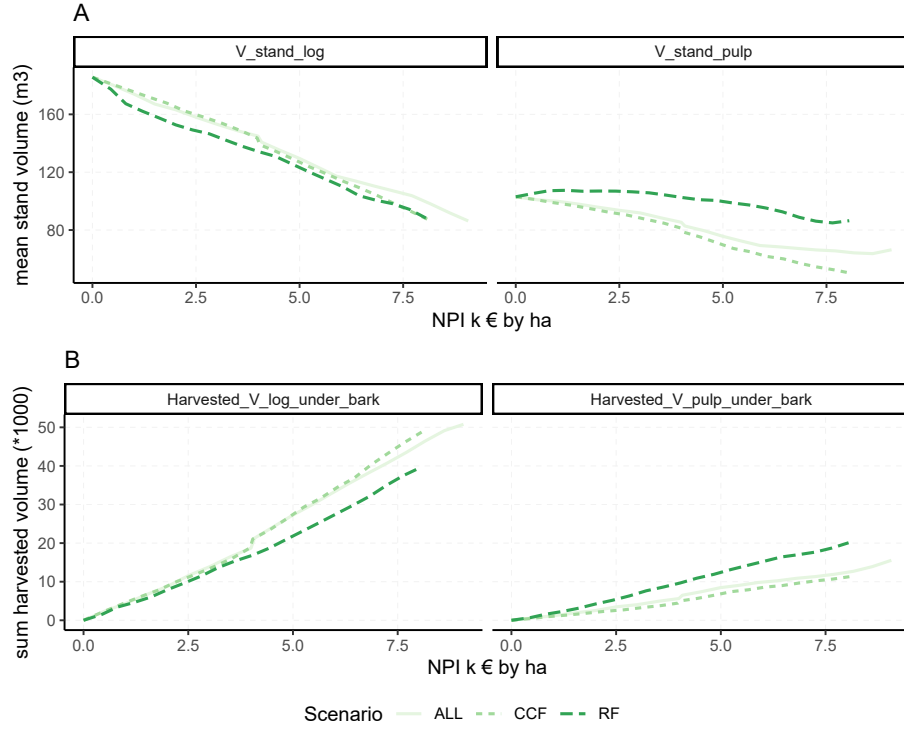


Figure 4: A. Mean standing and B. harvested pulp and log timber under three types of management regimes over harvest intensity gradient

Timber volume at wind risk

Increasing harvesting levels lowers the amount of the available timber at any time step to be lost due to windthrows. Interestingly, the CCF regimes produces higher logs volumes, while RF has higher production of the pulp wood, which is in high demand by cheaper than log wood. The same trends are visible for harvested log and pulp volumes. For ALL management regimes, using all available management regimes, is located between two extremities. The highest mean log timber volume as available for the wind damage at lowest harvesting levels. Interestingly, under RF, low levels of timber extraction increase levels of the pulp standing volume. The highest amount of harvested log wood is produced by CCF regimes, while RF dominates in harvesting pulp timber (Fig. ??fig_4_plot_V_timber)).

The intensification of the harvesting levels increases the proportion of the pulp wood compared to log wood, especially in RF. In CCF, the proportion among standing log and pulp volume remains at the same rate (65:30) where the production of the log timber dominates. At the highest intensity of timber extraction, pulp wood creates up to 50% of the total standing volume See figure @ref(fig:fig_5_proportion_V_pulp_log).

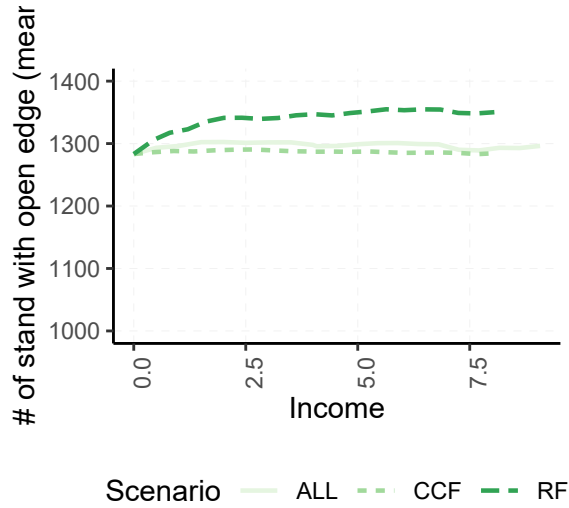


Figure 5: Yearly count of stands with open edge over the intensity gradient

Open stands frequency

RF regimes increase the amount of stands with open edge with increasing harvest intensity while CCF regimes maintain the same amount of open stands over the harvest intensity gradient. Intensive RF increases number of stands with open edge by 5%.

Changes in species composition

The intensification of the harvesting changes the stand species composition over time (Fig. ??). Intensification of the harvesting favorize the proportion of the Norway spruce and others (deciduous) tree species instead of Scots pine, which likely in turn increases wind risk over the stands.

Discussion

Wind (10 years return level of max wind speed REF) are estimated the same over 100 years as well as temperature sums. How does could affects the results?

In spite of inherent stochasticity of the wind and damage phenomena at all spatial scales can be successfully modelled combining spatial spatial datasets and ground earth observation data (Suvanto et al. 2019). Interpret Suvanto's map: there are 3 limitations: use values as relative to each other - instead of exact probability valuesm, interpret the map as relative differences in damage vulnerability Damage probabilities do not refer to complete damage of the stand – damage can be only poartial, in some part of the stand (not spatially expicit) map erepresent the forest vulnerability to the wind, but it is impossible to predict the exact locations of future wind disturbances, given uncertainties in future wind occurences

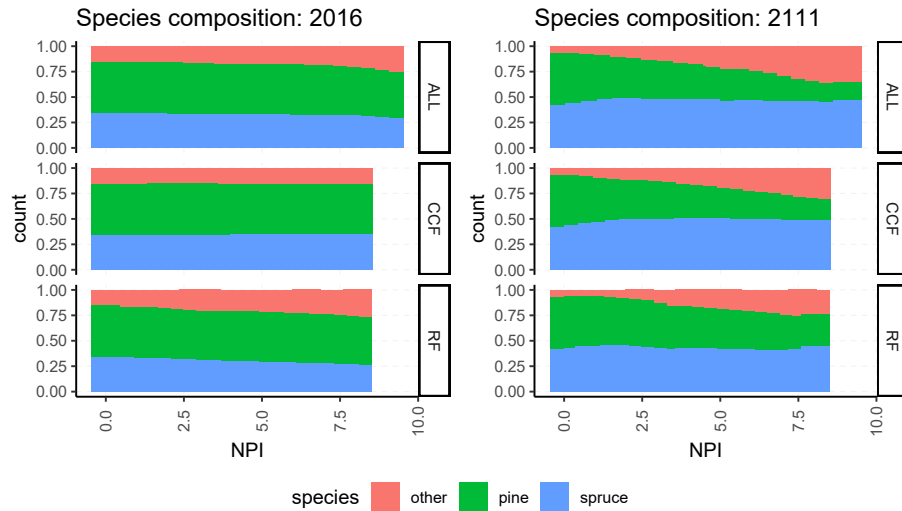


Figure 6: Changes in species composition under different management groups and harvest intensity. (The ALL scenario leads to highest economic gain, therefore values for CCF and RF are missing from plot)

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