Silver Fir (*Abies alba* Mill.), a Raising Queen of the Woods: a Brief Overview of Fir's Ecology, and Impact on Soil and Silviculture

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Abstract

Ongoing climate change is the main of many factors driving huge changes in forestry all over Europe. On one hand the rising temperatures allow higher volume increments of many tree species but on the other hand forest evapotranspiration is less and less often compensated by enough precipitation leading to stressing of trees. Huge dieback of allochthonous Norway spruce (Picea abies (L.) H. Karst.) stands in central Europe is an example of insufficient soil water availability through recent growing seasons. Autochthonous stands show both better resistance and resilience and so do mixed stands. Silver fir (Abies alba Mill.) is one of Europe's most important woody species both in ecological and economical aspect. It has gone through a significant change in its representation in Czech forests through last two centuries though, starting at around 20% and currently moving around 1,2%. Fir can effectively stabilize forest stands thanks to its deep root system and it can also lift water from deeper soil levels into topsoil making it available for itself and other trees even of different species. The roots can also improve the soil's physical conditions and connect to many mycorrhizal fungi species. Fir can grow in mixture with many other commercial tree species (i.e. Fagus sylvatica L., Picea abies (L.) H. Karst.), positively affecting their seeds' germination or volume increment. It is not yet known for sure what is the meliorative effect of fir as most science work focused on topsoil without studying mineral soil layer. As for topsoil, the fir creates significantly less litter but of very similar chemical and physical properties.

Keywords: *climate change, melioration, mixed forests, Norway spruce, roots, stabilization*

1 Introduction

All over the world the average annual temperature is rising but the amount of precipitation is staying the same with difference in its distribution (IPCC, 2021). The climate extremes caused by climate change (Gulev *et al.,* 2021) are more and more intense and frequent (Begović *et al.,* 2020; Popa *et al.,* 2024). The rising temperatures cause higher trees' volume increments on one

https://doi.org/10.11118/978-80-7701-024-5-0085

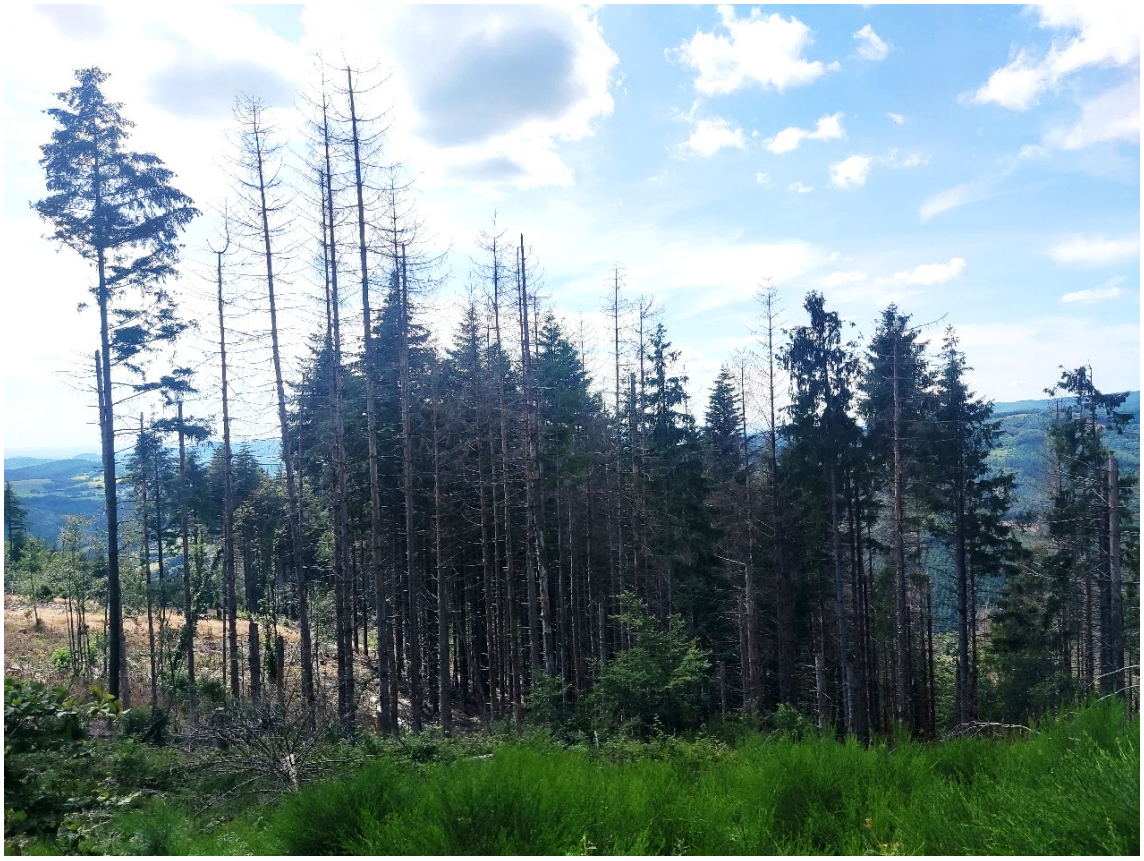

Fig. 1: *Silver fir monospecific stand showing die back in central France*

hand but higher evapotranspiration (Rahmati *et al.,* 2023) on the other hand, often causing insufficient soil water availability during growing seasons making them vulnerable to pathogens (Cienciala and Melichar, 2024). The forest ecosystems can be stressed by lack of available water showing different symptoms from loss of vitality, through embolism, to premature defoliation (Schuldt *et al.,* 2020; Frei *et al.,* 2022). Silver fir has gone through a period of dieback in the second half of last century caused by synergic effect of many factors from which SO_2 gaseous emissions seem to be the strongest, even stronger than climate (Elling *et al.* 2009; Diaci, 2011). Fir hasn't been specifically supported in our forests for around 200 years (Filipiak *et al.,* 2023) in synergy with unfavorable conditions caused by mentioned pollution, forest management and game population increment (Vrška *et al.*, 2009), leading to its significant forest representation reduction from around 23% (Málek, 1983) to actual 1.2% (MZe, 2023).

2 Regeneration

As a shade strongly tolerant climax species (Filipiak *et al.,* 2021; Novák and Dušek, 2021), silver fir can grow under canopy for many years, even decades without losing its vitality (Úradníček, 2010). Fir is sensitive to sudden canopy removal as it takes the trees a few years to acclimate making fir sensitive to rapid and strong direct light intensity increment (Čater and Diaci, 2017). Considering artificial regeneration, it is possible to affect the young trees' direct sunlight acclimatization via previous cultivation methods (Robakowski *et al.,* 2021). Fir's regeneration is generally problematic because of ungulates as they repeatedly damage the trees making it impossible for them to grow into canopy (Häsler and Senn, 2012; Frei *et al.,* 2024).

Fig. 2: *Fir natural regeneration on a stump*

On the other hand, fir shows great resistance to fungi after being mechanically damaged by game (Kohnle and Kändler, 2007). Another limiting factor of regeneration can be before mentioned insufficient water availability caused by too little precipitation as a much more important climatic factor than temperature (Subotić *et al.,* 2005). Silver fir on the other hand seems to be more drought tolerant than Norway spruce showing ability to acclimate to drier conditions (Piedallu *et al.,* 2023).

3 Mixed forests as an effective adaptation too

Fir is one of fundamental European tree species in terms of mixed forest stands (Caudullo *et al.,* 2016; Dobrowolska *et al.,* 2017; Hilmers *et al.,* 2019). It has been proven that spruce mixed stands increase their resistance and resilience meaning they could be a tool for supporting Norway spruce showing dieback all over Europe (Jactel *et al.,* 2017; Honkaniemi *et al.,* 2020). Norway spruce has been highly planted throughout whole Czech Republic without respecting its ecological conditions from 2nd half of 18th century creating monospecific even-aged stands leading to large area spruce stands dieback during last 10 years especially on their allochthonous sites (Bednář, 2016; Erber, 2019) while spruce shows better adaptation ability on its autochthonous sites, generally in mountainous forests (Hartl *et al.,* 2014). Most often used management connected to even-aged stands was clear-cut system which creates unsuitable conditions for many species' natural regeneration, especially of shade tolerant species, for example silver fir (Dobrowolska *et al.,* 2017). An advantage of mixed stands is that different species may occupy different niches (Uhl *et al.,* 2013) and can help each other for example by lifting water from deeper soil layers up to topsoil like silver fir does (Magh *et al.,* 2018) or by bringing more water to the soil surface during precipitation thanks to smooth bark like European beech does (*Fagus sylvatica* L.). Mixed stands even show better

Fig. 3: *Rich structured european beech and silver fir forest in western Croatia*

volume increment and lesser radial growth variability when managed correctly (Remeš, 2006; Schütz, 2002; Vacek *et al.,* 2021; Ray *et al.,* 2023). It has been also shown that both silver fir and Norway spruce represent better seed germination under each other in mixed stands (Hofmeister *et al.,* 2008).

4 Silviculture and growth

Fir's radial increment has increased significantly since late 20th century with reduction in NO_3 and SO_2 emissions and increase in temperatures as most probable factors (Bošeľa *et al.,* 2014). Declining trees presenting lower foliar nutrients concentrations show stronger relations between climate and growth and lower oxygen isotopes concentrations than non-declining trees (González de Andrés *et al.,* 2022). Čavlović *et al.* (2015) found that un-even aged forest structure promotes silver fir stands regeneration after stress. Fir also shows better diameter increments in stands with lesser stand density and basal area of overtopping trees, while tree diameter seems to be most important variable for fir's radial growth (Bončina *et al.,* 2023). Thanks to its high shade tolerance fir can naturally regenerate and prosper even in small stand gaps where other species can't even survive (Muscolo *et al.,* 2017). It also prefers un-even

Fig. 4: *Rich structured mixed forest of silver fir and deciduous trees*

aged rich structured forests suitable for its regeneration and growth (Ficko *et al.,* 2016; Dujka and Kusbach, 2020). In terms of height fir seems to grow until around 80 years with maximum between 50 and 60 years and then it accumulates significant diameter increments (Tudoran *et al.,* 2021). In the past fir's radial growth represented significant variability caused probably by nitrogen availability in soils (Pinto *et al.,* 2007) which is not actual anymore as there's nitrogen exposition (Carvalheiro *et al.,* 2019) showing positive effect on fir's radial growth (Bis and Dobrowolska, 2012).

5 Forest stabilization, melioration

Silver fir grows relatively deep root system starting as a tap root and then changing to heart-shaped able to penetrate also hard soils (Fér and Pokorný, 1993; Úradníček *et al.,* 2009; Třeštík amd Podrázský, 2017). Thanks to its deepest rooting out of our native coniferous species (Novotný *et al.,* 2010), fir is affected by windthrow rarely (Třeštík and Podrázský, 2017). It is a fundamental species for stabilization of hard soils and gleysols (Šindelář *et al.,* 2005). Silver fir is also an important species for maintaining resilience and stability of many mountainous stands in Europe (Frei *et al.,* 2024) as well as a prevention of avalanches and soil erosion (Tinner *et al.,* 2013; Vitasse *et al.,* 2019).

Silver fir's stand stabilization effect is indisputable but its effect on soil is still in question. It has been referred to as meliorating species but lately it has been found that fir's litter has similar chemical composition and create similar humus conditions as Norway spruce (Podrázský *et al.,* 2022) with slightly better nutrient availability (Podrázský *et al.,* 2024).

Fig. 5: *Mountainous European beech and silver fir forest in Snežnik, Slovenia*

Significant difference with Norway spruce is that silver fir creates significantly less litter in mature stands (62 vs 81 t/ha) (Podrázský *et al.,* 2022). Fir could also positively affect soil by its deep and wide root system by growing through soil and improving its physical conditions (Šindelář *et al.,* 2005; Kacálek *et al.,* 2017; Dušek *et al.,* 2020). A higher polysaccharide of both plant and microbial origin has been found in fir's rhizosphere (Bartoli *et al.,* 1993).

6 Mycorrhizal associations

Mycelium works as a network connecting trees and fungi (Teste *et al.*, 2009) transmitting nutrients and water (Teste *et al.,* 2010). Silver fir has a big potential for ectomycorrhizal fungi biodiversity support as it connects to at least a few dozen fungi species (Mrak *et al.,* 2020). Fir shows association with more fungi species on newly occupied agricultural land than Scotch pine (*Pinus sylvestris* L.) does (Waźny, 2014). Connection between fir and fungi is relatively fast as ectomycorrhizal associations are made within one generation (Comandini *et al.,* 1998) showing differences along fir's phonologic phases (Unuk *et al.,* 2019).

7 Conclusions

Silver fir is a very important species of whole Europe except its northern in terms of both ecology and economy. It grows in mixtures with many deciduous and coniferous species and creates mycorrhizal associations with dozens of fungi species. Mixed forests show better resistance and resilience to climate change supporting existing secondary spruce stands. Firs also positively affect forest stands by stabilizing them and creating un-even structures which are then suitable for their regeneration and growth thanks to their high shade tolerance.

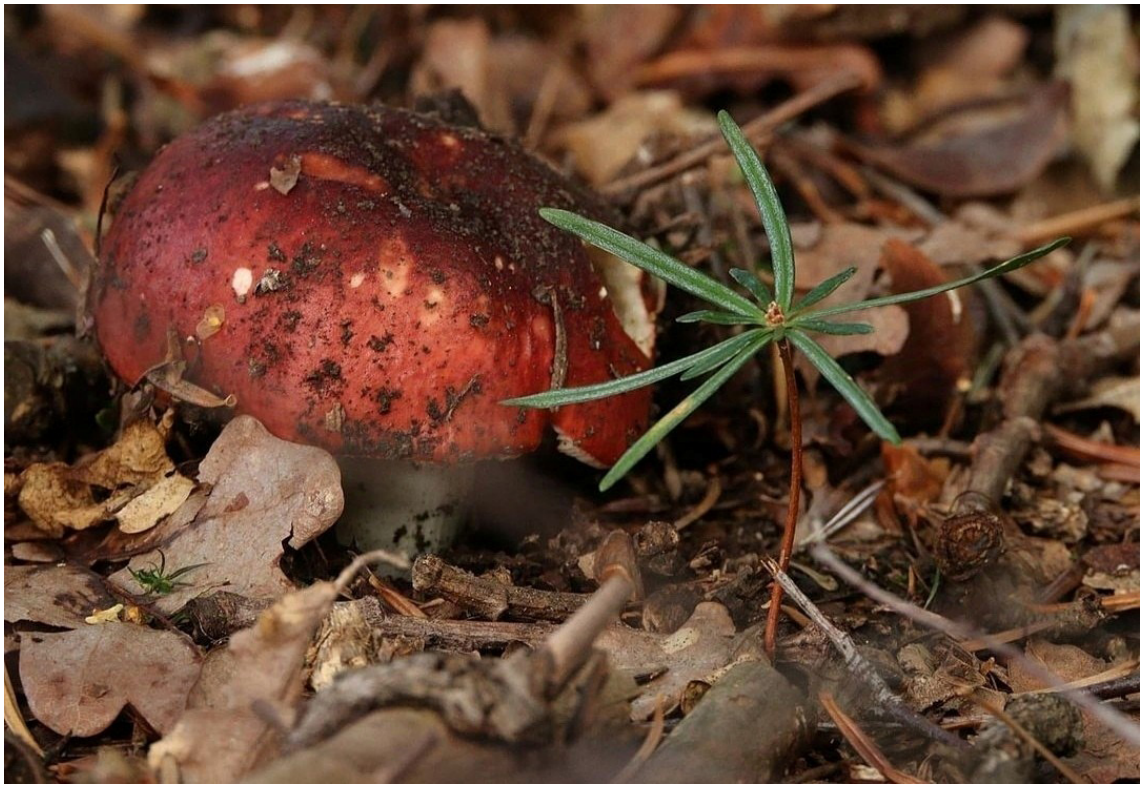

Fig. 6: *Silver fir natural regeneration next to a Russula sp.*

They can naturally regenerate and prosper even in small forest gaps that are unsuitable for other species' survival. A danger for fir regeneration are ungulates who commonly mechanically damage fir terminal buds and insufficient precipitations. In the past, fir has gone through a significant reduction of its forest representation because of synergy of factors most probably lead by SO_2 emissions.

Silver fir creates significantly less litter than Norway spruce, but their chemical conditions are similar. Silver for on the other hand positively affects the stands by its deep root system improving soil's physical conditions and allowing fir to lift water from deeper soil layers into topsoil. Because of its stabile root system, it is a fundamental species on many mountainous or heavy soil sites and can also prevent avalanches. Firs seem to be able to both occupy new sites thanks to mycorrhizal associations and grow as a climax species thanks to their shade tolerance. They show a big potential for adaptations against climate change in terms of growing mixed species that often show both higher volume increment and vitality.

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Acknowledgement

This contribution was prepared within the framework of the project QL24010275, Jedle bělokorá jako dřevina pro druhové přeměny lesních porostů ČR a vliv uplatněných obnovních sečí v interakci s podmínkami lesních stanovišť na její růst, vitalitu, odolnost vůči fytopatogenům a vývoj mykorhizních asociací.

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