Silver lime (Tilia tomentosa)

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Silver lime (*Tilia tomentosa*), a moderately drought-tolerant, thermophilous tree species of South-eastern Europe is considered suitable for the future.

assisted migration climate change non-native tree species habitat function lime forests oak forests complementarity gamma diversity European beech forests elevational gradient

1. Introduction

Climate change with increasing temperatures and seasonal changes in the precipitation regime will affect the characteristic tree species composition of Central Europe by inducing range shifts of tree species and by increasing tree mortality [1][2][3]. First and foremost, the naturally dominant European beech (*Fagus sylvatica* L.) will be affected [4][5][6]. Increased tree species mortality, however, may also contribute to diversifying the tree species portfolio [7][8] with positive effects for forest stability and multifunctionality [9][10]. In this respect, the introduction of non-native tree species originating from warmer climates and measures such as assisted migration have been discussed to maintain forest functionality [11][12]. Thereby, investigating tree species from regions where the climate already resembles projections for future climates in Central Europe can give important insights on the suitability of new tree species adapted to future trajectories [13][14].

Silver lime (*Tilia tomentosa* Moench) is native to South-eastern Europe and characterized as thermophilous. It is regarded as a possible future forest tree species in Central Europe originating from analogous climate regions [13][15]. Its native range mainly covers the south-eastern edge of Central Europe, much of the Balkan peninsula and north-western Turkey. As the northern distribution limit, Hungary and north to north-western Romania are mentioned [16][17][18]. Currently, it is a well-known horticultural tree species in urban environments across Europe [16][19]. The species is characterized as fairly drought-tolerant and drought-resilient. It can tolerate precipitation values as low as 500 mm, when equally distributed across the year, and mean annual temperatures between 10.0 and 11.5 °C [16]. In mixed oak-hornbeam-lime stands affected by severe droughts, silver lime was able to recover its crown faster than other admixed tree species [20]. It regenerates by seeds or by resprouting even under a closed canopy, it is characterized by a fast growth rate in the first five to six decades and is resistant against pathogens [16]. First establishment trials in Central Europe show a low mortality of seedlings and successful establishment in the first years after planting [15]. Its preference for soils with a relatively good water holding capacity in the native range [18], however, raise questions concerning drought limitations under more frequent and intense droughts.

The introduction of non-native tree species also aims for a successful ecological integration in the new range. The fact that *T. tomentosa* was part of the Central European vegetation before the last ice age [21][22] and its relatedness to the Central European *Tilia* species [18] may represent good preconditions for the adaptability of Central European biodiversity to silver lime. Nevertheless, to adequately assess the suitability and functioning of new tree species in the future, solid analyses in the species' native range are required to understand potential impacts on native biodiversity. In South-eastern Europe, *T. tomentosa* shows a broad ecological range. It is associated with mesophytic oak forests of *Quercus petraea* s.l. as well as with thermophilious oak forests of *Q. cerris* and *Q. frainetto* and is often admixed in stands formed by various *Acer* species, *Carpinus betulus, C. orientalis, Castanea sativa, Fraxinus ornus* and *Ostrya carpinifolia* [23]. In marginal sites of European beech (*Fagus sylvatica*), it is also part of beech forest communities [24][25][26]. Under specific conditions, it can form monodominant forests e.g., on northern slopes with neutral to slightly acidic soils and relatively high soil moisture. Such lime forests, listed as the European Union Habitat type 91Z0 (Moesian silver lime woods), often have a rich spring flora [27]. *T. tomentosa* can also reach dominance after intensive or deficient forest management activities or following natural disturbances due to its pronounced resprouting ability [20][28][29]. Pure stands have also been promoted for honey production in former times across the Balkans and Northern Tukey [30]. According to Jacquemart et al. [31], *T. tomentosa* has a higher nectar sugar concentration than *T. platyphyllos* and *T. codata* and offers more flowers, more nectar, and more pollen than other *Tilia* species. It is a late flowering *Tilia* species and could therefore complement the native earlier flowering species of Central Europe. Like European beech, pure stands of *Tilia* species are characterized by a low light availability [32], with the bark of the stems being susceptible when suddenly exposed to direct sunlight. This may explain the strong association of silver lime with more shady high forests compared to coppice forests despite its good resprouting ability [33]. It is, however, not well known to what extent *T. tomentosa* may provide alternative habitats for mesophytic, shade-demanding species that require a stable forest microclimate under changing climatic conditions [5].

To understand patterns of establishment of *T. tomentosa* in its native range, its effects on plant species diversity and composition in thermo- to mesophilous forests and its potential functionality for understorey diversity in a changing climate, we conducted vegetation surveys along three elevational transects in western Romania (study areas Milova, Maciova and Eşeslniţa) covering a natural, climate-induced vegetation gradient from thermophilous oak forests in the lowlands to mesic montane beech forests. Due to its favourable influence on the internal forest environment and on stand productivity, silver lime was promoted in Romanian silviculture as an admixed species mainly in mesophytic oak forests [28][34].

2. The Effect of Lime on Plant Species Diversity and Composition (A Case Study)

T. tomentosa had a neutral effect on plot-based plant species richness up to a canopy cover of ca. 40% indicating its suitability as an admixed tree species. In mixture, the good litter quality and rapid litter decomposition of *T. tomentosa* [18][20][35], as also found for other lime species [36][37], contributes to soil quality and even to species richness [38]. Above a canopy cover of ca. 40%, as a potential result of frequent disturbances and forest management, plot-based species richness decreased presumably due to limited light availability preventing the establishment of a herb and shrub layer [39]. Here, lime seems to function like European beech in Central Europe that can lead to a reduction in understorey plant species diversity with increasing abundance [38][40]. Even though we found no difference in total canopy cover between forest types or an effect of lime cover on mean light indicator values per plot (data not shown), light seems to be an important factor for reducing species richness when lime expands its tree cover. The indicator species identified for lime forests in western Romania (in combination with beech or oak forests) showed on average slightly lower light indicator values than indicators for beech or oak forests alone.

Lime-dominated forests were particularly species-poor in Milova and Maciova both for alpha diversity at the plot level and for forest type gamma diversity. Under the relatively humid conditions, silver lime was either dominant itself (Milova) or was associated with competitive beech and hornbeam (Maciova) that are known to produce shady conditions under the canopy [41]. With increasing EQ in lime forests (Maciova < Milova < Eşelniţa), gamma diversity on the other hand increased in this forest type. Thus, under optimized climatic conditions for beech (average EQ in Milova = 21.8 for beech forests), lime forests may decrease the regional diversity of forest landscapes under scenarios establishing lime at the expense of beech forests. With decreasing climate humidity, replacing beech by lime forests can either keep gamma diversity of forest landscapes constant (Maciova) or can increase it (Eşelniţa) and may therefore be considered an option for the future. Thereby, silver lime may be able to expand the range of typical species of the order *Fagetalia* in Central Europe such as *Galium odoratum, Mercurialis perennis* or *Lamiastrum galeobdolon*. These species may benefit from a dense canopy and from moist forest microclimate conditions within lime forests. On the other hand, lime forests in Milova and Eşelniţa rather resembled mesophytic oak forests of *Carpinetalia betuli* and showed transitions to thermophilous communities with species of the order *Quercetalia pubescenti-petraeae* (e.g., *Cornus mas, Lathyrus niger, L. venetus, Sorbus torminalis*) underscoring their transitional function toward thermophilic conditions.

However, the lime forests in all three study areas were less species rich in terms of alpha and gamma diversity than oak forests (though for Eşelniţa not significantly). This shows the importance of oak forests for biodiversity and a potential negative effect of lime on this biodiversity. Chudomelová et al. [42] for example demonstrated the impact of an expansion of *Tilia cordata* into steppic oak forests in the Czech Republic. A reduced light availability led to a loss of many typical oak forest and open land species. Similarly, Mölder et al. [43] showed how an expansion of beech reduced herb layer diversity in mixed broadleaved forests due to a reduction in light transmittance indicating some similarities for both tree species when it comes to impacts on forest biodiversity. In addition, species numbers of herbivorous insects [44] and saproxylic beetles [45] detected for the genus *Tilia* are rather similar (in fact slightly lower) to species numbers of beech but much lower compared to oak, even though all tree species have some specialized herbivores.

Thus, an introduction of silver lime cannot compensate for the potential loss of all native tree species in the future, in particular not for native oak species. It can, however, maintain functions of beech forests under a changing climate by providing a dense canopy and a moist forest microclimate and by allowing mesophilous and mesothermic woodland plant species to occur in warmer forest landscapes. This functionality of silver lime also reflects its ecological range in the native distribution area being associated with meso- to thermophilous oak species [18][20][26][28][29] and with European beech [24][25].

3. Conclusions

Our results from a natural beech-oak ecotone on the south-eastern edge of Central Europe, where *T. tomentosa* is a native forest tree, indicate that an establishment of silver lime can be successful on deep neutral soils with a relatively good water holding capacity if the competitive strength of beech is reduced e.g., after disturbances. Up to a tree cover of 40%, silver lime showed no effect on plot-level plant species richness showing its potential as an admixed tree species. When dominant, alpha-diversity of the herb layer was reduced. In general, lime forests were characterized by a lower alpha and gamma diversity of plant species compared to oak forests. Particularly for shade tolerant species, however, the dense canopy of lime forests can maintain habitats for mesophilous and mesothermic species and can extend their range into warmer landscapes. At the same time, lime forests provide habitat for thermophilous species when climatic humidity decreases.

Based on our results, silver lime may be regarded as suitable for future silviculture in Central Europe with a potential particularly as an admixed species. Noteworthy are its beneficial effects on ecosystem services, e.g., ameliorated soil properties [18], forest microclimate [39], ecosystem resilience, post-disturbance recovery of forest carbon [20], late-summer nutrient-source to pollinators [31], and its relatively low potential for invasiveness and hybridization [19]. Considering the presence of *T. tomentosa* in Central Europe in the last interglacial [21][22], assisted migration measures would support the potential re-expansion of this tree species from south-east to northern Central Europe. Nevertheless, a potential introduction is unadvisable close to protected areas left for natural development [46] and in open oak forests [42] to avoid unwanted forest habitat and biodiversity changes. In addition, decreased growth responses in recent years detected in western Romania, the availability of only few establishment trials in Central Europe until now [15], and the risk of being exposed to unsuitable conditions in the introduced range (e.g., late frost, [47]) that have not been explored yet, underline the need for more research with this and other thermophilous tree species. The uncertainties of a non-native species also underline the importance of focusing on native tree species in Central Europe and their functionality under changing climatic conditions such as native *Tilia* species [36][37], *Acer campestre* or *Sorbus* species [48] that may be better adapted to future climatic conditions than the current main timber species.

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