How do Central European forest stands respond to climate change - Review

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Abstract: Current global climate change alters the behaviour of species, and this can be also witnessed when investigating the species composition, the structure and the processes of different ecosystems. Today a growing number of researches deal with the climatic exposures of forests, mostly focusing on the responses of the dominant climate susceptible tree species and the direct and indirect impacts of climate change experienced in forests. During literature review we looked for publications investigating the experienced impacts of climate change in our region including responses witnessed in growth, mortality and regeneration capacity of tree species. From different climatic exposures the impacts of increased CO_2 level, nitrogen deposition, milder winters and more droughty and drier summers can be experienced most in our region. Publication's statements on the changes of tree species and forest stands have been grouped and summarized according to the characteristic exposures. Based on the literature data it can be stated that climate change variously alters the tree species composition, mixture ratio and diversity of forest stands and the outcomes of other forest dynamic processes through vitality, production and competitiveness of different tree species.

Keywords: climatic exposure; deciduous forests; climate sensitive tree species; forest dynamics; beech; oak; weather extremities

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Introduction

In the last 30-40 years atmosphere, oceans and surface of the Earth became warmer significantly increasing the average temperature values of the last 1400 years. In addition, the carbon and nitrogen cycles of ecosystems also substantially changed (Galloway 2004, IPCC 2014). At the same time, average global surface temperature values vary to a great extent, which can be experienced not only at the decade level but even on an annual basis. According to the weather data recorded since 1901, the average amount of precipitation increased in the temperate zone of northern hemisphere, but its distribution within the year considerably changed compared to the former period (IPCC 2014). Since 1950 the frequency of weather extremities has also changed. Most importantly, the number of colder weather extremities decreased, while the occurrence of extreme warm weather conditions increased, and we also had to face a growing number of heavy rainfall events in more regions (IPCC 2014, IPCC 2019). According to the different CO_2 emission scenario based climate model simulations, these weather conditions are expected to get more extreme in the future. What is more, there are some regions (e.g. the North Pole) which respond much faster than other regions of Earth. It is expected that due to global warming heat waves are getting longer and more frequent (IPCC 2014), making it even more difficult for the living creatures to survive the dry periods (Allen et al 2010). According to the recorded weather facts (the extremely hot and dry periods), 2018 can be considered a new reference year regarding hot droughts in Europe (Buras et al. 2019).

Regional datasets and tendencies are in line with the global changes, and can provide more accurate data at the local level (Szelepcsényi 2014, Dobor et al. 2015, 2016, Spinoni 2015). Regarding Europe as a whole,

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the Mediterranean Region is the most threatened area, since not only the more frequently appearing droughts but also the increasing risk and occurrence of forest fires are expected there (Lindner 2010). At the same time, huge regional and local differences can be witnessed when analysing climate change. Hlásny et al. (2014) draw the attention to the "hotspots" of the Carpathian region, which may be highly vulnerable to climate change due to the loss of biodiversity. Climate models predict stronger Mediterranean weather characteristics, more frequent weather extremities and significant increase of the average temperature (even by 4°C) in Hungary by the end of the century (Krüzselyi et al. 2011, Spinoni et al. 2015). Based on the different model simulations, it is expected that there will be less cold weather extremities but more warm ones, and drought periods will be also longer (Pieczka et al. 2011). Although there are some uncertainties regarding the amount and the distribution of precipitation, it seems that the amount of rainfall will change, its intensity is expected to increase, and the winter months will be the wettest ones (Bartholy et al. 2011, Horányi et al. 2011, Bihari et al. 2018).

For the natural ecosystems climate change will appear in the form of climatic exposures. According to the definition of the Intergovernmental Panel on Climate Change (IPCC), climatic exposure means "the nature and degree to which a system is exposed to significant climatic variations" (Füssel & Klein 2006). The various species respond to climatic exposures differently due to their unique sensitivity levels. This leads to complex and diverse outcomes affecting the species composition and the productivity of forest ecosystems (Lindner et al. 2010).

The most important questions to be answered by this review are the following:

Regarding growth, mortality and regeneration capacity of the trees living in the natural forests of Hungary ...

- What are the major characteristics of climate change (experienced in the last decades) in our region?
- How will these changes – as climatic exposures – affect the native tree species and the natural forest stands of our region?

Materials and Methods

During literature review we focused on those papers, which were investigating the impacts of the major climate factors changed in recent decades and influencing the behaviour of trees, stands and processes of natural deciduous forest ecosystems in our Pannonian region and surroundings. We searched for publications focusing on the impacts of the following climatic exposures: increasing of atmospheric carbon-dioxide and nitrogen deposition; summer drought stress; milder winters, longer vegetation season and earlier onset of spring and shift of temperature and precipitation's regime. Articles presenting the impacts of the specific climate exposure through the examples of Central European, temperate zone and climate zonal forests of Hungary had priority. Those professional articles have been taken into account that investigating directly the already experienced impacts of exposures.

The statements of the selected papers were tagged and grouped according to the main types of climatic exposures: A) increasing global atmospheric CO_2 concentration; B) increasing reactive atmospheric Nitrogen (Nr) deposition; C) more frequent mild winters, earlier onset of spring and the extension of the growing season; D) increasing temperature with no water limitation; E) Increasing summer temperature and drought stress and F) indirect effects of increasing summer temperature and drought stress. Afterwords the impact statements were ordered, grouped and summarized with no weighting, however the number of references shows a higher degree of agreement.

Results

The main impacts of climatic exposure on trees and natural forest stands have been arranged, assessed and summarized in Table 1.

Table 1. Thematic overview of the main impacts of climatic exposure on trees and natural forest ecosystems caused by the recent climate change – summarized results of a review.

Climatic Exposure	Impact on Forests	References
A) Increasing global atmospheric CO_2 concentration by 15-20 ppm / decade since 1980 (NOAA 2019)	Increased growth of young tree stands if no other limitation factors (i.e. light, water, nutrient) occur, but mature forest trees (oak, hornbeam) generally did not show growth enhancement in response to elevated CO_2 level, partly except of beech.	Asshoff et al. (2006), DeLucia et al. (1999), Hickler et al. (2015), Laubhann et al. (2009), Norby et al. (2005)
B) The reactive atmospheric Nitrogen ($N_{reactive}$) deposition almost tripled the natural level by the early 1990s. According to the projected trend it is to double more by 2050 Galloway et al. (2008)	Increase of $N_{reactive}$ deposition can enhance ecosystem productivity (mostly in N-limited regions) through fertilization and decreases biodiversity (i.e. herb layer) through acidification and eutrophication.	Fowler et al. (2013), Galloway et al. (2008) Fowler et al. (2013), Galloway et al. (2004), Sybryn et al. (2018)
	Nitrogen deposition generally shows a significant positive impact on tree growth, although the N and the C cycles of the ecosystems are complex and coupled processes. Too much nitrogen slows down forest growth.	Etzold et al. (2020), Komarov et al. (2012), Laubhann (2009)
C) More frequent mild winters, earlier onset of spring and the extension of the growing season. The average advance of spring was 2-4 days/decade between 1951 and 2000 in our region. An increase of mean annual temperature by 1°C led to the extension of the growing season by 5. days	Spring warming has a strong impact, but the combination of winter and spring warming has the greatest impact on earlier budding (beech, birch and oak).	Ahas et al. (2002), Fu et al. (2012), Menzel et al. (2006), Chmielewski & Rötzer (2001)
	Indirect impact: warm temperatures can decrease the winter mortality of forest pest insects, thereby shortening generation time (generalization is difficult because of the various species-specific responses)	Pureswram et al. (2018)
	Pest insect populations can react fast to the favourable periods and condition deterioration of their host trees.	Csóka et al. (2018), Hirka et al. (2018), Mátyás et al. (2018)

Table 1. *Continued*. Thematic overview of the main impacts of climatic exposure on trees and natural forest ecosystems caused by the recent climate change – summarized results of a review.

Climatic Exposure	Impact on Forests	References
D) Increasing temperature with no water limitation Trend: Significant warming tendencies are dominant at the period of 1961-2001, in the Carpathian Basin (Pongracz & Bartholy, 2006).	Increasing growth (basal area) of larger beech and pedunculate oak trees, but beech turned to decline since the 1960s due to the decreasing relative summer humidity in the Atlantic climate. Stable stand volume increment of mixed mountain forests, however significant changes in the growth dynamics at the species level: spruce dropped, fir rose, beech did not change.	Kint et al. (2012), Laubhann et al. (2009), Hilmers et al. (2019)
E) Increasing summer temperature and drought stress Trend: Heat waves in the Carpathian region between 1961-2010: four out of seven heat events occurred after 2000 (Spinoni et al. 2015).	Forest growth declined during drought, especially during more severe droughts in the drier climates. Beech is the most drought sensitive tree species compared to sycamore, Norway maple, sessile oak and common ash. Its growth decreases in the driest stands (less precipitation than 600 mm/year) since about the 1980s. Decreasing productivity by increasing aridity for beech, hornbeam, sessile oak and Turkey oak.	Árvai et al. (2018), Führer et al. (2011), Führer et al. 2016), Gálos & Führer (2018), Gleason et al. (2017), Horváth & Mátyás (2014), Mátyás et al. (2018) Sáenz-Romero et al. (2019), Spathelf et al. (2014), Zimmermann et al. (2015)
F) Indirect effects of increasing summer temperature and drought stress	Change of dominance among trees species, beech was more competitive but less drought tolerant than oak until annual precipitation fell below 540 mm in a 100-year-old mixed forest.	Mette et al. (2013)
	Drought induced self-thinning (mortality) of sessile oak stands in Hungary	Berki et al. (2014), Berki et al. (2016), Herczeg et al. (2018), Árvai et al.

Table 1. *Continued*. Thematic overview of the main impacts of climatic exposure on trees and natural forest ecosystems caused by the recent climate change – summarized results of a review.

Climatic Exposure	Impact on Forests	References
F) *continued* Indirect effects of increasing summer temperature and drought stress	Expanding distribution area at leading edge of manna ash tree due to good natural regeneration capacity on drier sites	Molnar & Czúcz (2009)
	Reduction of macroclimatically suitable areas for beech and sessile oak in the following decades near the xeric distributional limits	Czúcz et al. (2011), Salamon-Albert et al. (2016), Illés (2018)

Discussion

Increasing CO_2 and atmospheric Nitrogen deposition can enhance tree growth and ecosystem productivity

Although increasing atmospheric CO_2 levels and reactive Nitrogen deposition increase forest productivity at many places, researches revealed that such responses are site, age and species specific. According to the researches investigating young hardwood and pine stands, trees treated with air enriched with CO_2 grew more intensively that the surrounding ones; and their net primary production (NPP) also significantly increased together with their fine-root. In drought years there was no difference between the growth intensity of the treated trees and those of the control group (surrounding trees without any CO_2 treatment). However, in the long run decreased production has been observed, which could be traced back to the limited access to minerals (DeLucia et al. 1999). Other outdoor CO_2 chamber experiments also found that younger tree stands reached higher NPP values, exceeding the reference value with 23% on the average (with significant standard deviation) (Norby et al, 2005). It has been verified at more locations that water supply has a greater impact on the growth intensity of the different tree species. Usually, higher CO_2 concentration level leads to increased productivity but in many cases the effects of CO_2 have been overestimated because at areas with water deficiency less growth can be observed, or decline can be experienced (Hickler et al. 2015). Asshoff et al. (2006) investigated the changes of the sum of the basal area of 5 dominant European tree species in old forest stands. They found that in the investigated 4 years long period increased CO_2 level did not lead to the enhanced production of the tree species. Although beech reached outstanding growth levels in the first year, this growth advantage disappeared due to the drought experienced in the third year. During the research also phenological variables (e.g. budding and defoliation) have been analysed, which turned to be species specific, but could not be linked to the increased CO_2 levels.

"By now, food and energy production of [industry] increased the rate of anthropogenic Nitrogen creation tenfold compared to the value of the late 19th century." (Galloway 2004, Galloway 2008, Sybryn et al. 2018) Komarov and his colleagues (2012) modelled the changes of productivity according to two different climate scenarios and forestry inventory data in three forest sites in Russia under continental climate. Due to the growing level of N-deposition increased productivity can be expected besides the spread of deciduous tree species in the mixed tree stands (Komarov et al. 2012). N-deposition increased the growth of all the investigated dominant tree species (beech, sessile oak, pedunculate oak, fir and spruce) in European forests (Laubhann et al. 2009).

Milder winters and the earlier onset of spring cause less winter mortality among forest pest insects, and accelerate budding

Milder winters and the earlier onset of spring can be witnessed all over Europe leading to the lengthening of the vegetation period and the growing risk of late frost damages. Milder winter weather facilitates the survival of phytophagous insects, consequently larger populations and increased insect damages can be witnessed in the vegetation period (Pureswarm et al. 2018, Csóka et al. 2018). In the absence of the critical winter periods the range of insects also changes enabling the conquest of new territories (Pureswarm et al. 2018, Csóka et al. 2018). The average advance of the summer half year was 2-3 days/decade in Europe. The phenological characteristics of the species also responded to this in accordance with the earlier spring temperature increase. On the other hand, defoliation takes place one day later/decade on the average (Menzel et al. 2006). Based on the data of the European phyto-phenological database, budding starts 4 weeks earlier in Western and Central Europe compared to the reference period (1951-1998) of the database. Differences can be observed in the timing of spring phenological events in the mountainous regions, which is mostly the result of the diverse microclimatic patterns and the different altitude levels (Ahas et al. 2002) Temperature manipulation experiments have been used for investigating the phenological events of beech, oak and birch seedlings in winter and spring periods through the simulation of warming. Budding started earlier in the case of all the three tree species when spring warming has been simulated, while winter warming seemed to have no effects at all (Fu et al. 2012). Milder winter weather facilitates the survival of phytophagous insects, consequently larger populations and increased insect damages can be witnessed in the vegetation period. (Csóka et al. 2018, Hirka et al. 2018). In the absence of the critical winter periods the range of insects also changes enabling the conquest of new territories (Pureswarm et al. 2018, Mátyás et al. 2018).

Altered growth dynamics of trees due to increasing temperature

The connection between more environmental variables (e.g. average temperature, precipitation, carbon-dioxide level and nitrogen level) and the growth of stand forming tree species (beech, sessile oak, pedunculate oak, spruce and fir) have been investigated in Europe. Increasing average temperature had a positive impact on the growth of all the tree species, except for spruce (Laubhann et al. 2009). In Austrian mixed forest stands – consisting of pine and deciduous trees – higher average temperature combined with lower precipitation levels did not alter the productivity of the trees. In the mixed forests researched by Hilmers and his colleagues the diminishing population of spruce was counterbalanced by the increased production of other tree species (e.g. beech and silver fir) (Hilmers et al. 2019). Similarly, the basal area growth of temperate tree species has been investigated in areas under Atlantic climate between 1901 and 2008. According to

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the data, the productivity of pedunculate oak continuously increases, while in the case of beech productivity started to decrease from the 1960s due to the drop in relative humidity values during the summer periods in the Atlantic regions (Kint et al. 2012).

Increasing drought stress decreases productivity, and can induce higher mortality among the more susceptible tree species

The characteristic exposures of climate change include the more frequent occurrence of warmer and drier summers and longer drought periods accompanied with heat waves. The intensity of growth significantly decreased during drought periods, especially at arid and semi-arid locations. In regions with sufficient water supply competition had a greater impact on production. This could be also observed in drought periods when the impact of aridity has not been enhanced by high temperature. (Gleason et al, 2017). By using the aridity index, calculations have been made on the future changes of the habitat conditions and the production of the different tree species in Central Europe. From the analysed weather variables late spring temperature and total annual precipitation turned to be of special importance. Since the amount of available water affects the production of organic matter, decreased productivity, worse health status and lower density values can be expected in the case of some of the species at areas with high forestry aridity index (FAI) values (Salamon et al. 2016, Führer et al. 2011, Gálos & Führer 2018, Sáenz-Ronero et al. 2019). In Hungary, the spread, the ecological needs and the climate sensitivity of more stand forming tree species have been investigated, and based on the results their future has been predicted for the next decades according to the expected climatic changes. These forests and tree species are located close to the xeric edge of the temperate deciduous forest zone in the Carpathian Basin, therefore some of the currently dominating tree species (beech, sessile oak and Turkey oak) may disappear from huge areas, and the structure and the characteristic of the forests may fundamentally change (Spathelf et al. 2014). A further finding of the researches is that habitats suitable for beech will be limited to smaller areas by 2050, and the ideal habitats meeting the ecological needs of beech – being a stand forming species today – will virtually disappear from Hungary by the end of the century a (Czúcz et al. 2011, Illés 2018). Beech is susceptible to aridity, and this can be also witnessed in the changes of dominance relations. Drier and warmer weather forecasted in Central Europe decreases the competitiveness of beech, consequently the ratio of drought tolerant tree species (e.g. maples and ashes) and the dominance of sessile oak are expected to increase (Mette et al. 2013, Zimmermann et al. 2015, Árvai et al. 2018). From the indicator species signalling drier climate manna ash can be highlighted. Data on its historical and recent spread and the latest related observations have been summarized by Molnár and Czúcz (2009). According to their research, the spreading and the increasing ratio of the species can be witnessed in the forest stands of the North Hungarian Mountains where habitat conditions were not so ideal for manna ash earlier (Molnár & Czúcz 2009).

Conclusions

Climatic exposure caused by climate change is a complex process showing regional and local patterns. The major changes – increasing CO_2 concentration and atmospheric Nitrogen deposition, more frequent mild winters and earlier onset of spring, higher temperatures, and increasing summer drought stress – cause direct impacts, which sometimes counterbalance each other. Climatic exposure mostly alters growth dynamics, vitality and competitiveness of the trees, which are highly specific due to the ecological and trait profile and various sensitivity of different tree species. The more frequent appearance of forest pest insects and the new invaders may cause severe indirect impacts on trees. We found it during the literature review that in the majority of the cases tree specific growth and mortality related changes can lead to considerable shift in density and mixture ratio of trees in the stand. Much less evidences are available on the close relation between climate exposure and success of tree regeneration. It is clear that besides climate exposure the establishment and the regeneration of the trees also greatly depend on several other factors (i.e. canopy closure, propagulum sources, competition relationships, browsing effect of the stock of game, etc.) in the natural forest stands. Finally, we can conclude that investigating and exploring changes in tree specific growth and mortality as the possible outcomes of climate exposure are promising fields of research.

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