26: Forest and Climate Change

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Intended learning level: Advanced

Purpose of the chapter:

In this chapter the role of forests in the climate system and under climate change will be highlighted. The development of European forests as carbon sinks or carbon sources is described, as well as the impact of climate change on European forests.

NOTE: this text is a complete draft, which will be further revised and edited following review by the EUROSILVICS Project Board

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26.1 Introduction

Climate change has become a main driver of environmental change due to a significant rise of global mean surface temperatures and extreme weather events. Globally, the mean annual surface temperature has risen by more than 1.3°C in 2011-2024 compared to pre-industrial conditions (1850-1900), and has been proven to be human caused to a high degree (Betts et al., 2023). Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years. In Europe, temperature rise is higher than the global average, and within Europe south-western, central and north-eastern Europe as well as the alpine regions experienced the highest increase (IPCC, 2021). When considering extreme weather events, the frequency and magnitude of warm extremes has increased whereas cold extremes have become less common (EEA, 2008). Correspondingly, we observed a severe summer drought in 2003, 2015 and 2018-19, followed by a sharp decrease in forest vitality in Central Europe (Senf & Seidl, 2021) and several severe forest fire seasons in Southern Europe (Portugal 2003 and 2017, Greece 2007, 2018, 2021 and 2023, France 2022). Less clear are wind climate tendencies, with some recent evidence that high intensity storms may become more frequent with global warming (Haarsma 2021; Outten and Sobolowski, 2021), whereas general storm frequency may not necessarily increase. However, windstorms are the most important disturbance agent affecting forests in Europe (Senf & Seidl, 2021; Patacca et al., 2023) and some devastating storm events like 'Lothar' (Central Europe 1999), 'Gudrun' (Southern Sweden 2005), 'Kyrill' (Germany and Slovakia 2007), 'Klaus' (France and Spain 2009), and 'Vaia' (Northern Italy 2018) have caused substantial losses of standing wood volume during the last thirty-five years (Patacca et al., 2023). Besides climatic effects, the high volume of timber damaged by storms was enhanced by the record high standing volume in European forests (MCPFE, 2007), providing increased storm damage potential (Gardiner et al., 2013).

Future warming depends on future GHG emissions, with cumulative net CO_2 dominating. The assessed best estimates and very likely ranges of warming for 2081-2100 with respect to 1850–1900 vary from 1.4 [1.0 to 1.8] °C in the very low GHG emissions scenario (SSP1-1.9) to 2.7 [2.1 to 3.5] °C in the intermediate GHG emissions scenario (SSP2-4.5) and 4.4 [3.3 to 5.7] °C in the very high GHG emissions scenario (SSP5-8.5). Projected global GHG emissions from NDCs (Nationally Determined Contributions) announced prior to COP26 would make it likely that warming will exceed 1.5°C and also make it harder after 2030 to limit warming to below 2°C (IPCC, 2021). Continued GHG emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales. Many changes in the climate system become larger in direct relation to increasing global warming. Continued global warming is projected to further intensify the global water cycle, and very wet and very dry weather and climate events and seasons (e.g., Mann et al., 2017; Lorenz et al., 2019; Felsche et al., 2024). So which type of climate will we get in the future in Central Europe? Probably not just a shift to a warmer climate such as from temperate oceanic or subcontinental to subtropical Mediterranean, but a climate where still severe (late) frosts are occurring but with higher mean and extreme temperatures, therefore causing a higher demand for evapotranspiration (see Figure 26-1, IPCC, 2001). The climatic water balance, especially in the vegetation period, will fall below zero in many regions in Europe. Days with extreme temperatures (e.g., 30° C) will rise in number.

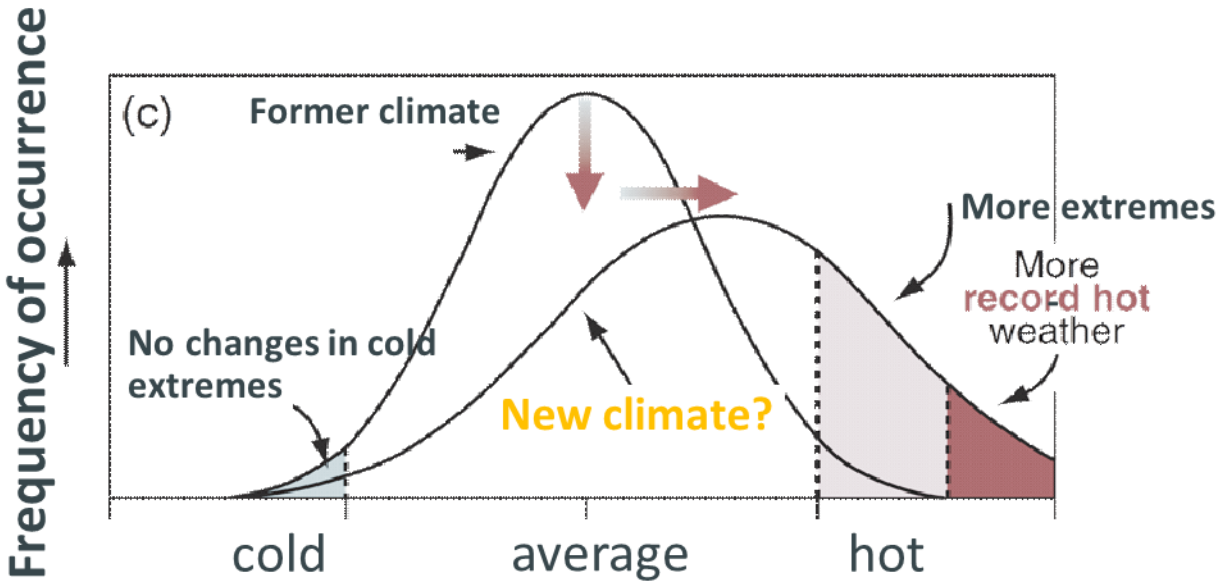

Figure 26-1: *Magnitude and direction of climate change (according to IPCC, 2001, Third Assessment Report).*

Due to climate change and forest damages in many parts of Europe (e. g. Hlásny et al., 2021; Patacca et al., 2023; Seidl & Senf, 2024) there are current debates on forest crises, 'disaster forest', or the need for a paradigm shift in forestry (Spathelf, 2021). There are doubts as to whether the path that European forestry has taken for many decades is the right one (‘Der Holzweg’, Knapp et al., 2021), the forestry sector and forest ownership as a whole are accused of serious mistakes, indeed they are considered to be part of the problem (Bode, 2019). In the meantime, since some decades close(r)-to-nature forest management as a sustainable and ecosystem-based form of forest management has become an attractive and promising model for many forest owners to stabilize their forests and provide diverse ecosystem services (Stiers et al., 2020; Brang et al., 2014; Larsen et al., 2022).
Nevertheless, a current line of conflict and debate is the question of whether forests should continue to be used sustainably or whether the forest ecosystem, with its undisputed value for a wide range of human needs (climate protection, refuge of biodiversity, provider of other so-called ecosystem services), should be placed under extensive protection with the exclusion of utilization (Jandl et al., 2019). In other words, a ‘breather’ for the forest that enables it to return to stable development through processes of self-regulation which increases its resistance and resilience (Aszalós et al., 2022). This hope that ‘nature-based solutions’ are the way out of the forest crisis contrasts with the fact that our forests are mostly old cultural landscapes that have been used and modified by humans for centuries (Küster, 2010; Muys et al., 2022). However, it is crucial to understand that the number of suitable tree species is decreasing due to climate change (Wessely et al., 2024) and that assisted migration may be necessary to sustain forest ecosystem services (Chakraborty et al., 2024).
choose tree species that do not absorb and disseminate these metals, such as common ash (see, among others, Mertens et al. 2007).

An excess of nitrogen leads to imbalanced mineral nutrition, resulting in nutrient deficiencies and increased susceptibility to other infections, as seen in cases of watermark disease in white willow (De Vos et al., 2007). Additionally, it is suspected that high nitrogen load in forest ecosystems increases susceptibility to fungal infections, making the planting of many conifer species on nitrogen-rich agricultural lands very risky due to root rot. Furthermore, trees along the coast are exposed to high salt concentrations, limiting the choice of tree species. In low-lying areas along rivers, flood tolerance can be an important selective factor (see Glenz et al., 2006). Finally, biotic factors can also restrict tree species selection. The local presence of the elm bark beetle, which acts as a vector for *Ophiostoma* fungi (causing Dutch elm disease), makes elm a prohibited choice in many places. However, white elm (*Ulmus laevis*) appears to be less susceptible to infestations and might be planted under limited risk.

26.2 Carbon budgets – European forests as sink or source[1]

26.2.1 Carbon storage and sink

Forests can contribute significantly to the global carbon cycle and climate change mitigation by sequestering carbon from the atmosphere and storing it in forests (forest biomass and soil) and in wood-based products (with long life-cycles), and also through the use of forest biomass to substitute for fossil-fuel-intensive materials, products and fossil energy (Nabuurs et al., 2017; Leskinen et al., 2018). This is also the case in Europe, where the majority of forests are managed. Forest management has largely influenced the present tree species composition (Spiecker, 2003) and wood production potential (Rytter et al., 2016; Verkerk et al., 2019) of forests, and will continue to do so for the coming decades (e.g., Koehl et al., 2010; Lindner et al., 2014).
In Europe, the forest area and carbon storage have both increased since the 1950s for several reasons. The forest area has increased by about 30% between 1950 and 2000, and by 9% since 1990 up to the present (Forest Europe, 2020). This has occurred through natural forest expansion and the afforestation of low-productivity agricultural lands (Palmero-Iniesta et al., 2021). The ratio of annual harvested timber to the total annual increment of forests for a long time was below 80% across Europe, remaining relatively stable for most countries until around 2015; recent studies reveal that tree harvest in Europe's forests increased since then (Ceccherini et al., 2020; Hyyrynen et al., 2023; Lerink et al., 2023; Seidl & Senf, 2024). Additionally, improved forest management practices and changing environmental conditions (e.g., nitrogen deposition, climate warming and the elevation of atmospheric CO2 concentrations) have increased the carbon sequestration and storage in European forests (e.g. Pretzsch et al., 2014). The growing (carbon) stock of European forests has clearly increased more rapidly over the last few decades than the forest area (e.g., 17.5 million ha between 1990 and 2015), as the average volume per hectare has been increasing. It should be noted, however, that the recent increase in forest disturbances has regionally reversed this trend (Seidl & Senf, 2024) and some countries like Czech Republic have lost substantial shares of their growing stock volume (Hlásny et al., 2021; Washaya et al., 2024).

There are significant distinctions among the forest carbon sinks in different parts of Europe due to large differences in the forest area and structure (age and tree species composition). These are related to differences in the prevailing climatic and site conditions, the intensity of past and current forest management activities, and the level of socioeconomic development (EEA, 2016). In Northern Europe, where the share of forest area is higher than in other parts of Europe, the forest landscapes are dominated by mainly coniferous and even-aged forests. In Central and Southern Europe, broadleaved

[1] Chapter from Kilpeläinen & Peltola (2022)

deciduous and mixed evergreen forests are more common (Forest Europe, 2020). Overall, the forests are more productive and have higher volumes of growing stock in Central and Western Europe than in other parts of Europe. In Western Europe, plantations of fast-growing, often exotic tree species show very high growth rates. Forest productivity is, nowadays, limited by the length of the growing season and the relatively low summer temperatures in Northern Europe, whereas in Southern Europe, it is limited by water availability, with many forests also being located on sites with low potential for wood production. The prevailing environmental conditions, current forest structure, management traditions and different socioeconomic factors have also affected the intensity of forest management. Management intensity varies from fully protective for biodiversity conservation, to uneven- and even-aged rotation forestry, which affects forest carbon sequestration and storage. Forest ownership structures, and targets set for forest management and its possible constraints, have also, together, affected the intensity of forest management and harvesting and thus the development of carbon sinks and storage and the wood production potential of European forests (Rytter et al., 2016; Verkerk et al., 2019). Currently, ca. 50% of forests in the EU are privately owned, with about 16 million private forest owners (Nabuurs et al., 2015). In forest management, different ecosystem services may also be emphasised to a greater degree, depending on set targets and constraints in different regions (Hengeveld et al., 2012; EEA, 2016).
The growing (carbon) stock of European forests (see Figure 26-2) is currently double what it was in the 1990s. The carbon-stock increases in forests and wood products, and the average annual sequestration of carbon in the forest biomass, was 155 million t in 2020. Currently, EU forests sequester ca. 10% of Europe's greenhouse gas (GHG) emissions (Forest Europe, 2020). When considering the carbon storage in wood products (an additional ca. 12 Tg C year-1) and the substitution effects of the forest sector, additional 3% of the total GHG emissions in the EU28 are avoided (Nabuurs et al., 2015; Korosuo et al., 2023).

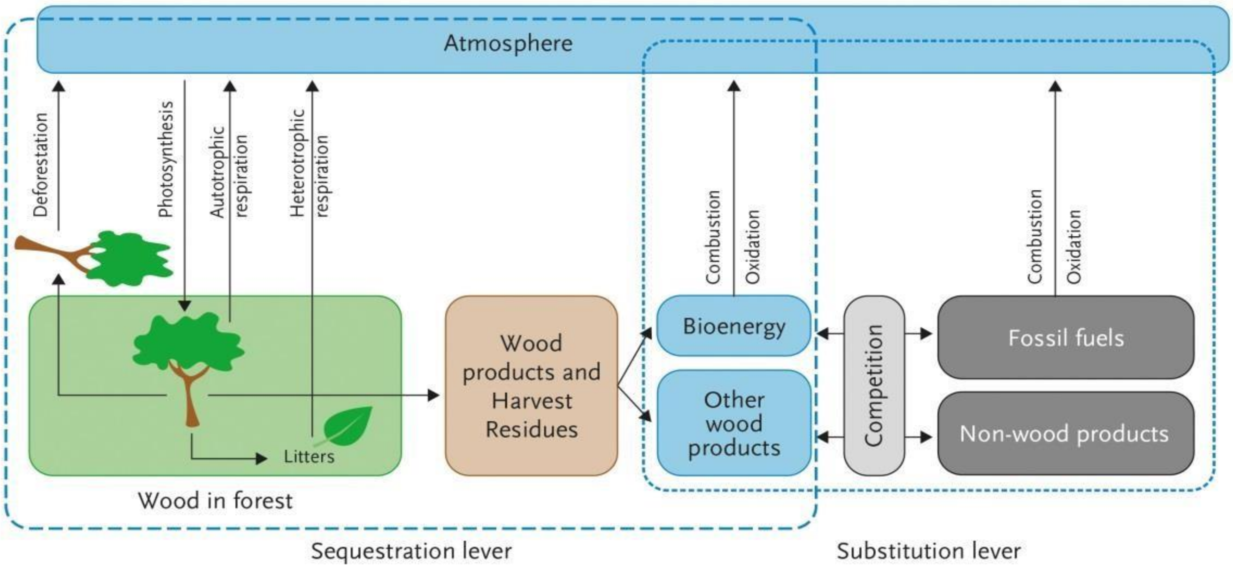

Figure 26-2: *Carbon sequestration in the forest system (forest pool, products and substitution) according to Nabuurs et al. (2015).*

Furthermore, woody biomass provides ca. 6% of the energy consumed in the EU (Eurostat, 2020). On the other hand, the first signs of saturation in the European forest carbon sink were recognised in the 2010s (Nabuurs et al., 2013). Today, after several severe disturbance years in Europe's forests and e.g., the loss of 5 % of the Norway spruce volume, it is far more uncertain, whether the carbon sink contained in European forests (and the broader forest sector) will remain at the same level as before (McDowell et al., 2020).

26.2.2 Carbon Dynamics in a Forest Ecosystem

The carbon dynamics in a forest ecosystem comprise the carbon uptake by trees (and ground vegetation) in the above- and belowground forest biomass, and carbon release through the autotrophic (metabolism of organic matter by plants) and heterotrophic (metabolism of organic matter by bacteria, fungi and animals) respiration. The forest ecosystem is a carbon sink if it absorbs more carbon from the atmosphere than it emits, resulting in an increase in the carbon storage of the forest (forest biomass and soil). Moreover, the forest store can be expanded by utilising wood in durable products. The carbon dynamics of a forest ecosystem are controlled by environmental (climate, site) conditions, and the structure (age, stocking, tree species composition, etc.) and functioning of the forest ecosystem.

The carbon sequestration and stock of forest biomass may vary greatly in a forest ecosystem over time, these are controlled by the initial stand characteristics, the type and intensity of management (e.g., forest reproductive material, thinning and fertilisation) (Routa et al. 2019) and the length of the rotation period (Lundmark et al. 2018). Whereas around 45 % of the forest carbon is stored in the aboveground biomass, 55 % are part of the soil (organic layer and mineral soil until 90 cm depth) (Luyssaert, S. et al., 2010; De Vos, B. et al., 2015; Wellbrock et al., 2016). The carbon stock in soil is generally relatively stable, although it is affected by carbon inputs from litter fall and carbon outputs from the decay of litter and humus, the latter representing earlier litter input of unrecognisable origin (Kellomäki et al., 2008). The decomposition of humus and litter contributes significantly to soil carbon emissions at the beginning of the rotation period, but in the later stages of stand development, carbon input is prevailing (e.g., Kilpeläinen et al., 2011). Generally, for most of the duration of stand development, the stands act as carbon sinks.

Management intensity affects the carbon sequestration and stocks in forests through changing the structure and functioning of an ecosystem. A managed forest ecosystem sequesters carbon as trees grow, but loses carbon in harvesting. By comparison, in unmanaged forest ecosystems (e.g., old-growth forests), the carbon dynamics are affected by the age structure, the mortality of trees, natural regeneration and the ingrowth of seedlings in canopy gaps (Luyssaert et al., 2008). The annual growth rate of trees can be higher in managed than in unmanaged (intact) forest landscapes (Kellomäki, 2017; Moomaw et al., 2020). Older forest stands can store more carbon, but the rate at which they remove additional carbon from the atmosphere is substantially lower, and can even become negative as the mortality increases and exceeds the regrowth (Gundersen et al., 2021). On the other hand, devastating abiotic (e.g. wind storms and forest fires) and biotic (e.g., insect outbreaks) disturbances may cause a sudden decrease in carbon sequestration and storage in forest ecosystems. The extent and speed of change depends on post-disturbance management (whether damaged wood is salvaged or left in the forest to decay).

The use of appropriate, site-specific regeneration methods and materials (e.g. improved reproductive materials with better growth rates and survival), the proper timing and intensity of pre-commercial and commercial thinnings, and forest fertilisation on sites with limited nutrient availability, have been proposed as ways of increasing carbon sequestration (and timber production) over one rotation in e.g. France and boreal forests (Serrano-León, H. et al., 2021; Haapanen et al., 2015; Hynynen et al., 2015). According to Olsson et al. (2005), nitrogen fertilisation may also increase the sink and storage of carbon in upland (mineral) soils in Norway spruce stands due to the simultaneous increase in litter production and decrease in the decomposition of soil organic matter and heterotrophic respiration in the soil. However, there have been contradictory findings on the effects of nitrogen fertilisation on the decomposition of soil organic matter and soil respiration (e. g. Högberg et al., 2017). The maintenance of higher stocking in thinnings, together with longer rotations, may also increase the carbon stock in forest ecosystems over a rotation period (Liski et al., 2001; Routa et al., 2019). Overall, carbon sequestration and storage may be increased in forests in different ways by modifying current forest management practices. However, the same measures may affect forests differently.

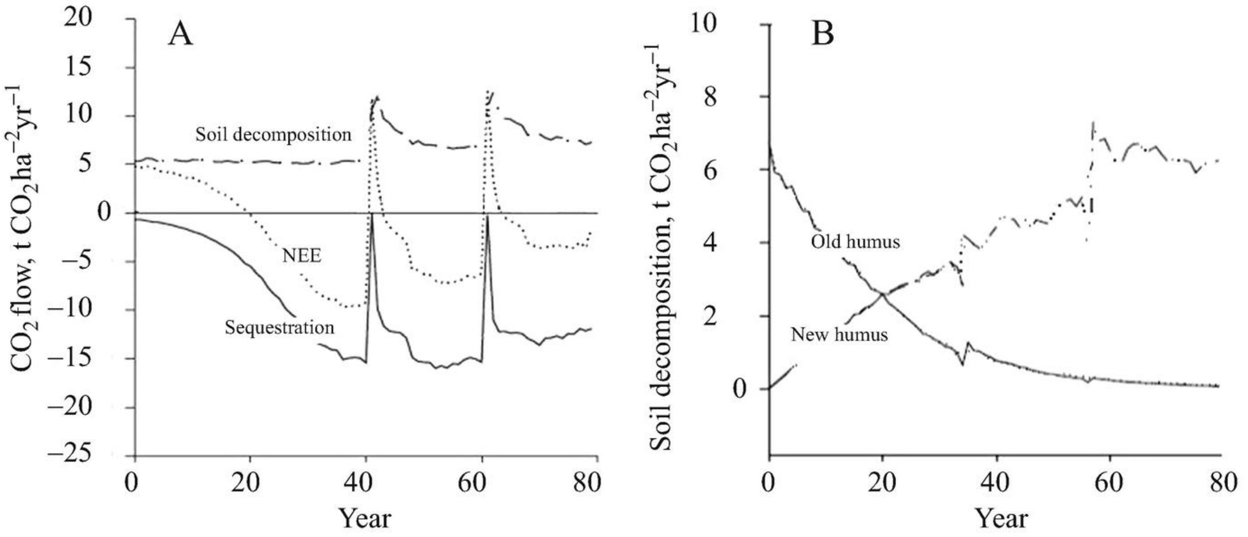

Figure 26-3: *Development of annual carbon flows of net ecosystem CO_2 exchange (NEE: carbon sequestration + soil decomposition; according to Kilpeläinen & Peltola, 2022).*

Figure 26-3 provides an example of the development of the net ecosystem CO_2 exchange (NEE) of a boreal, even- aged Norway spruce stand on a medium-fertility upland site over an 80-year rotation period, based on the gap-type forest-ecosystem model SIMA (Kellomäki et al., 2008) simulations (Kilpeläinen et al., 2011). Seedling stands (2000 seedlings per ha) act as a carbon source over the first 20 years after a clearcut because the carbon sequestration is lower in young seedling stands than the carbon emissions from decaying humus and litter in the soil. As carbon sequestration increases, a stand becomes a carbon sink. The thinnings at ages 40 and 60 years produce peaks in the carbon emissions due to harvesting and the decay of logging residuals.

26.2.3 Mortality, including timber damage

Tree mortality is a natural, continuous process in the development of tree populations, usually with a variety of causes (complex of factors) and therefore difficult to predict. Compared to the rather slow growth processes of trees, mortality is often abrupt, with potentially drastic consequences for ecosystem development. A distinction is made between disturbance-related and competition-related mortality: disturbance-related mortality often has a random character (e.g., lightning strike, infestation by pests), while competition-related mortality is one of the fundamental processes of forest development and inevitably leads to a reduction in tree numbers as the size of the trees increases. The extent to which climate change, particularly drought and heat, affects the mortality of trees has been the subject of intensive research for some time. It has been shown that drought stress-related mortality - in various forest ecosystems worldwide - has been increasing for some time (Allen et al., 2010). Excess mortality (i.e., more than average disturbance related mortality), has risen by up to 500 % across Europe, particularly since 2016. Mortality is often preceded by years of tree senescence, which can be recognized by the declining vitality status (crown transparency classes of the forest health survey) and the decline in increment (Camarero et al., 2015).

Expected abiotic impacts of climate change may interact with indirect biotic effects like changing pathogen and pest regimes. In central Europe, an increased occurrence of insect damage (Ammer et al., 2006; Dobbertin & DeVries, 2008; Hlàsny et al., 2021) and latitudinal range shifts of biotic disturbance agents (Battisti et al. 2005) is anticipated. It is likely that forests in Europe will increasingly suffer from further novel pests, especially alien invasive species such as the Asian longhorn beetle (*Anoplophora glabripennis*, Krehan, 2008; Seidl et al., 2018) and the pine wood nematode (*Bursaphelenchus xylophilus*, Mota et al., 1999). In general, the disturbance risk under climate change is increasing (Seidl et al., 2017). Abiotic and biotic impacts interact with each other (e.g., Scots pine decline in the Swiss Rhone Valley, Rebetez & Dobbertin, 2004), but also with anthropogenic pressures of air pollution and atmospheric deposition of the past and today (Braun et al., 2003; Boisvenue & Running, 2006; Paoletti et al., 2007).

An illustrative and frequently used concept to explain the causes of mortality is the decline-disease theory (Manion, 1991). A complex of weakening, triggering and aggravating factors triggers a disease process and leads to the death of the tree. Weakening factors such as groundwater lowering or the lack of site suitability of a tree species reduce the vitality of trees. Drought stress or severe frosts have a direct influence on the vital functions of the tree and lead, for example, to severe loss of growth (triggering factors). Reinforcing factors such as insect damage are then ultimately the cause of the lethal weakening of the tree. Drought stress as one of the most important stressors in climate change varies greatly in its effect, depending on the tree species (deciduous trees, conifers) and age of the trees (young plants, old trees), the season of occurrence (spring or summer), or the intensity (frequency of succession). Increasing summer temperatures were identified as a mortality-increasing cause for all major tree species and mixing, on the other hand, reduces significantly the mortality risk (Bender et al., 2019; Brandl & Falk, 2019; Annighöfer et al., 2017).

In the forest health survey (WZE), which has been conducted annually in Germany since 1984, crown transparency is recorded separately by tree species as an indicator of vitality. Until 2017, the trees with significant crown transparency were on average in the range of 20-25 %, with a sharp increase to values of >35 % in 2019 and 2020. The WZE confirms the well-known fact among tree physiologists that older trees (e.g., over 60 years old) are more vulnerable and ultimately more severely damaged than younger trees. The difference is often more than 20 percentage points (BMEL, 2021). Crown transparency is weakly correlated with the dieback rate of the trees and ultimately the extent of the damaged wood. Between 2003 and 2017, the proportion of damaged wood in total felling was around 10-20 % (with the exception of storm Kyrill in 2007), and during the hot drought between 2018 and 2020, it shot up to a record high of over 70 % (Spathelf et al., 2022).

26.2.4 Productivity (timber yield)

Climate change may have positive effects on forest growth where growth has been limited by temperature and growing season, i.e., in the boreal zone and in the oceanic northwestern parts of Europe (Nemani et al., 2003). In turn, forests in the Mediterranean and South-central (continental) European regions, already limited by drought and heat, may be further impaired.

The wood volume stocks of forest ecosystems in Germany has risen sharply in the second half of the 20th century (Pretzsch et al., 2014; Spiecker et al., 1996). At the same time, harvests also increased, triggered by energy incentives for wood energy. The reasons for the growth increase are the higher nitrogen saturation of the sites, the rise in CO2, a longer vegetation period, but also improved forms of management such as the avoidance of litter raking or the mixture of tree species with complementary properties. The changed growth trends are reflected in an improved relationship between increment and tree size (referred to as relative growth rate and expresses the efficiency of growth), as well as between tree number and tree size (expressing the density of trees per unit area) (Pretzsch et al., 2014). This increase in increment led to an overall increase in productivity, i.e., the volume output of the forests in relation to age. However, it should be noted that the higher growth rates are associated with a reduction in wood density (Pretzsch et al., 2018).

There are currently increasing indications that further increases in forest productivity can no longer generally be expected in Europe in the future. On the one hand, the increasingly ageing forest stands are approaching saturating increment levels, and on the other hand the frequency and intensity of disturbances is increasing, for example in the form of mortality in medium-aged spruce forests (Bolte et al., 2021). This has far-reaching effects on the climate protection function of forests, as it means a decreasing sink capacity of the forest for storing CO2 (Nabuurs et al., 2013). The increasing likelihood of seasonal water shortage slows down tree growth: particularly for forests at lower altitudes (planar and colline levels) in Central Europe, which are particularly affected by hot temperatures and multiple dry years (hot droughts), a decline in growth is to be expected (Thom et al., 2023). But even with saturating sinks, the overall climate protection function could still increase if more wood products are used for long-lived wood products and circular value chains with recycling.

Model calculations based on the ForClim simulation model assume a decline in forest productivity at low altitudes in Switzerland by the middle of the 21st century (Huber et al., 2021; Bircher et al., 2016). Finally, a possible change in the composition of tree species due to climate change is likely, e.g., from previously vigorous conifer species to less productive Mediterranean oak species such as Turkey oak, can also lead to a reduction in productivity (Hanewinkel et al., 2013). However, although we may face more frequent disturbances with consequent loss of growing stock, in many cases the species will be regenerating. We do need to consider assisted migration, including with non-native species to compensate for the loss of spruce (Chakraborty et al., 2024).

26.3 Changes in the composition of tree species and their economic consequences

In the medium to long term, climate change will have an impact on the species distribution ranges in which the tree species are well suited to climate (Wessely et al., 2024). In so-called range or distribution models, the probability of occurrence of tree species is estimated with the help of climate and soil parameters. The projection of the distribution areas of spruce in Baden-Württemberg by the end of the 21st century, for example, assuming a worst-case climate scenario (RPC8.5), shows that e.g., Norway spruce only occurs in the high altitudes of the low mountain ranges (e.g., Black Forest) and only as a mixed tree species (Albrecht et al., 2019). Using a similar approach, a research group from Eberswalde University was able to predict a significant decline in the distribution area of beech in Brandenburg by the end of the century based on the SRES scenario A1B (Spathelf et al., 2016). According to this scenario, forests with beech as the leading tree species will only cover around 5 % of the forest area in Brandenburg in 2095.

For Central Europe, a certain range stability of the most important tree species can still be assumed for the next 10-20 years, at least if a moderate climate scenario (e.g., RCP4.5) is anticipated (FVA, 2022; Spathelf et al., 2016). However, by the end of the century, many coniferous forests (tree species spruce, silver fir and larch) in particular will be lost (Hanewinkel et al., 2010a). Ideally, as one tree species retreats, another species will take its place as a result of succession processes, as has been observed for around 15-20 years in the example of pine and the sub-Mediterranean downy oak replacing it in the inner Alpine dry valleys (Rigling et al., 2018). At lower altitudes in Germany, thermophilic tree species such as sweet chestnut, downy oak, Turkey oak and cedar in particular could become more widespread, while beech forests could migrate into the mid-mountain regions, primarily at the expense of spruce and pine (Wissenschaftlicher Beirat für Waldpolitik, 2021). Such tree species range development scenarios should already be taken into account today in forest conversion planning.

Range shifts of tree species have not only ecological but also economic consequences. In a European study, Hanewinkel et al. (2013) projected that European forests could decline in value by almost a third by the end of the 21st century compared to 2010 due to a shift in the tree species spectrum from conifers to deciduous trees with a focus on Mediterranean oak species. Moreover, a significant number of tree species will not be able to resist the climatic changes (i.e., especially under RCP8.5) during their whole lifespan in the 21st century. Thus, a significant tree species bottleneck might lead to strong negative impacts on timber production, carbon storage and biodiversity conservation (Wessely et al., 2024). For Baden-Württemberg, Hanewinkel et al. (2010b) calculated heavy losses in NPV (Net Present Value) by the end of the 21st century due to the expected dramatic decline in spruce. The possible decline in the volume of softwood will also have a considerable impact on the use of wood, particularly in the construction industry.

26.3 Synthesis

The World will face continuous climate change with still uncertain magnitude, but with high likelihood, the change of disturbance regimes will be an even more crucial factor shaping our forest landscapes in the future. Climate change magnifies the impacts of disturbance events, and a higher frequency and intensity of disturbances are very likely and have to be taken into account in forest management. Extreme climate events with unprecedented duration of drought and changing seasonal distribution of precipitation – shifting towards more winter precipitation and less in summer. Moreover, the number of days in the growing season with precipitation is also projected to decrease, with more heavy rainfall events. Consequently, availability of soil moisture, which is crucial for ecosystem productivity, will be limited more often, with drastic impacts on forest ecosystems. Hence, we might see increased year-to-year variation, and chances are that normal/good years may be overcompensated by disturbance pulse releases (c.f. Reyer et al., 2017).

Due to an increasingly saturated forest sink and a higher vulnerability to climate change of many forests, climate change mitigation through long-lived harvested wood products with potential to substitute fossil fuels and energy intensive materials become increasingly relevant during the transition period to carbon neutrality. Nevertheless, Sustainable Forest Management will become more volatile and difficult because planned harvests may no longer be always feasible, if fellings are increasingly dominated by salvage cutting. This is a major threat for the development of resilient mixed species stands.

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