FORBIO Climate

Adaptation potential of biodiverse forests in the face of climate change

Summary

Climate change is expected to have a large impact on the distribution, composition and functioning of forest ecosystems worldwide due to the limited migration and adaptation potential of trees. Creating resistant and resilient forests is thus a key challenge for forest management. It has been suggested that epigenetic mechanisms may increase the capacity of trees to survive in a changing environment, but the extent and importance of these mechanisms in seedlings and saplings are still unknown. Research has also shown that more biodiverse ecosystems are better buffered against disturbances. Yet, these studies were predominantly performed in grasslands. More insight into the adaptive capacity of trees and forests in their consecutive life and development stages, respectively, and the potential buffering effect of tree species admixing to climate change is thus urgently needed.

FORBIO Climate aimed at scrutinizing the adaptive capacity of particular tree species and predicting the future performance of these tree species under climate change in Belgium. The project focused on oak (*Quercus robur/petraea*) and beech (*Fagus sylvatica*), two tree species with high ecological and economic significance in Belgium (and Europe). FORBIO Climate capitalized upon multiple research infrastructures in Belgium and abroad (e.g. the FORBIO site in Zedelgem, the Belgian Observational Biodiversity Platform, the ORPHEE experiment in France, common gardens in Belgium and Denmark) to test the following hypotheses: (1) epigenetic inheritance mechanisms can increase the adaptive capacity of trees to climate change during the reproduction stage; (2) across subsequent tree development stages, tree performance is more resistant and resilient to climate change in more biodiverse forests.

The project was structured in five work packages (WPs). In short, WP1 provided past climate data that were linked to the measurements on seedlings, saplings and mature trees in WP2-4 to assess the effects of climate variation on tree performance. WP1 also provided simulations of the future climate. In WP5, drought and diversity responses were scaled up to a national level and stakeholders were inquired about their perception of climate change effects and adaptation.

In more detail, WP1 provided past and future climate data from selected weather stations and high-resolution Regional Climate models, respectively. Observational data from the Belgian climatological network for the period 1980-2016 were first subjected to quality control tests. Kriging using the topography as drift, and ordinary kriging were then used to interpolate the observational data on daily temperature and precipitation, respectively, on a regular 4x4 km grid over Belgium, resulting in the observational climate dataset. For the climate simulations, the Regional Climate Model ALARO-0 was used with a downscaling approach where atmosphere and land surface were modelled in a continuous way. First, the model was validated for the present climate conditions (1980-2010) by dynamical downscaling of a global climate model dataset at 4x4 km resolution. For the historical simulation (1976-2005), a constant value for the CO_2-equivalent was used; for the future simulation (2007-2100), the so-called Representative Concentration Pathways (RCP 2.6, 4.5 and 8.5) were implemented, which describe the radiative forcing from greenhouse gasses, i.e. the difference between insolation (sunlight) absorbed by the Earth and the energy radiated back to space. Climate change was then calculated as the difference between the historical and the RCP simulations. The model predictions indicated a consistent T increase of 0.3 to 4.2 °C, dependent on the RCP scenario, with a larger warming for the Ardennes compared to the rest of the country. Mean annual precipitation showed a slight increase by the end of the century due to more extreme precipitation events, especially in winter and autumn. Wind speed did not change in a clear way while relative humidity showed an indistinct but consistent decrease towards the end of the century.

The aim of WP2 was to quantify the epigenetic effects of parental temperature on seedling performance, using various warming treatments (soil warming, branch warming, translocation to

common gardens). Parental temperature influenced the germination success, bud phenology and growth of the seedlings and this effect depended on the environmental conditions in the offspring generation. Hence, there is a need to consider the life history and parental environmental conditions to predict the response of trees to climate change. We also investigated DNA methylation as a potential epigenetic mechanism for transgenerational effects. We used Methylation Sensitive Amplified Fragment Length Polymorphism (MSAP) analysis to examine the natural variation in genome-wide DNA methylation patterns within individuals plants of a single poplar hybrid clone (genotype). However, we could not confirm that methylation helps to explain the phenological changes mediated by the parental temperature. Further investigation is necessary using more powerful molecular methods like whole-genome bisulphite sequencing techniques.

WP3 quantified the impact of tree diversity and composition on the overall performance of oak and beech saplings and on the mitigation of drought stress. For this purpose, a drought experiment using rainout shelters was installed on the FORBIO-site in Zedelgem, examining the impact on sapling growth and vitality, abiotic soil variables, soil microorganisms and soil organic matter transformation. Overall, a 2-year 50% precipitation reduction did not affect tree growth but influenced soil biogeochemical processes, which could alter nutrient availability for trees in the long term. Several soil processes and microbial composition were affected by tree species admixing. This indicates that, in young forest stands, belowground processes might be more sensitive to drought and tree diversity than aboveground processes. Tree species admixing to oak and beech showed some degree of stabilizing effects against drought.

WP4 examined the performance of mature oak and beech trees under drought stress and quantified the contribution of tree diversity to the mitigation of adverse climate effects on mature tree growth. We selected triplets of oak and beech and cored dominant trees to measure the ring widths. Tree ring measurements were used to test whether mixing had an impact on individual tree growth, more specifically on the sensitivity of growth to stresses like drought. On a subset of the cores, the rings of 2001, with a normal summer, and 2003, with a very dry summer, were analyzed for ^{12}C and ^{13}C content, from which $\delta^{13}C$ was calculated, which is a measure for the extent to which the drought was experienced by the tree. Dendrometric measurements on the surrounding trees were used to characterize the neighbourhood of the trees in terms of competition and species composition. In mixed oak-beech stands, beech grew faster compared to its monocultures. However, a drawback of fast growth is the need for more water, which might cause them drying out the soil quicker. Yet, we have shown that mixing is *de facto* beneficial for the growth of beech trees in tough years (i.e., years of slow growth), regardless of whether this is caused by droughts or other environmental factors. Thus, the overall effect of tree diversity on the productivity of mixed beech stands remains positive. Oak, on the other hand, generally grew more slowly when mixed with beech, because beech is a better competitor. However, this disadvantage for oak became smaller in harsher conditions, and may even be reversed, for example on dry sites. In these cases, oak growth actually benefits from growing in a mixture with beech. This also means that, when conditions harshen, oak growth will be less affected in mixtures than in monocultures. In this sense, mixing can be seen as a safety measure for both oak and beech. An important output of this work package is the establishment of a network of eight oak-beech triplets, together with a collection of data on tree growth and neighbourhood. In fact, the sites already serve as soil sampling sites for other research on species mixing in forests.

WP5 acted on a more integrated level in terms of time, space and forest development stage, on the role of tree diversity in a context of climate change. In a first step, nation-wide effects of climate change on stand dynamics of beech and oak stands were investigated. Data of ICP Forests, the regional forest inventory of Flanders and Wallonia, the digital soil map of Belgium, the climate dataset obtained in WP1 and a digital terrain model were used to assess tree health and growth, to examine whether drought resilience was correlated with tree diversity and whether mixed-species stands can overyield monospecific stands. Crown defoliation of beech and oak has significantly increased since the 1990s. The severity of defoliation was lower at higher tree diversity levels when considering long-term responses to changes in temperature and precipitation. The observed shift from a negative to a positive effect of species richness on forest condition, caused by increased water stress, has never been reported from real ecosystems outside experimental conditions. Drought also caused a marked growth reduction in deciduous trees, especially for beech, although we found that trees growing in mixtures were more resilient to drought than those growing in monocultures. Second, a questionnaire was administered to inform on the perception of forest owners and managers on the vulnerability of forests to climate change and the extent to which specific actions to enhance the resilience of forests are being implemented in practice. We found that there is a marked imbalance between the large awareness about climate change impacts and the adaptation practices put in place by forest managers for coping with it, probably due to a lack of locally relevant and practical information. Third, a systematic review of the published literature on tree diversity effects in a climate change context is still ongoing.

Our results corroborate evidence that managing oak and beech forests to retain or increase tree diversity is a step forward to mitigate the vulnerability of these forests to climate change. Mixed stands grant managers with more options for future stand development, as they decrease the vulnerability posed on monocultures in light of future climate changes. Standardized, long-term monitoring of forest vitality is an effective method to detect climate change-induced and tree diversity-mediated trends in forest health and productivity. The continuous improvement in the quality of data that has been achieved so far has proven to be an effort that merits improved and extended continuation. Further research may focus on a wider range of tree species and multiple climate change drivers across various ecosystems to predict the response of trees to climate change better.

Keywords: climate change; epigenetics; *Fagus sylvatica*; *Quercus* sp.; tree diversity