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Editorial

Influence of Climate Change on Tree Growth and Forest Ecosystems: More Than Just Temperature

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Recent research has shown that climate change is already altering tree species ranges, mortality and growth rates. Analyses of the potential effects of climate change on tree growth in Europe, Asia and America have suggested that important timber species may lose suitable habitat in the following decades, and suffer adversely from a combination of warming trends and reduced growing season precipitation. In contrast, other species may actually expand their range and potentially show improved growth rates in parts of their existing range, or show potential for their use as commercial species as they are established in new regions. Research has uncovered species-specific growth responses to climate change, and the important role of topography and local adaptation. In addition, the complex interactions between tree growth and temperature, water, nutrients, and carbon dioxide are also modulated by inter- and intra-specific competition levels. The state-of-the-art currently focuses on understanding how forest ecosystems, and not only tree species, could respond to climate change. In this respect, the potential resilience of mixed forests towards changes in growing conditions could also be used to adapt forest management to the novel growing conditions that are slowly but steadily unfolding. Therefore, this Special Issue was launched to help advancing the current knowledge of how climate change can influence tree growth and forest ecosystems.

It is well established that greenhouse gases such as carbon dioxide or methane influence atmospheric temperature. Historically, climate warming has gathered the most international attention among the effects of climate change on Earth´s ecosystems. However, increasing the amount of gases such as CO_2, CH_4 and NO_x retained in the atmosphere will cause many other effects beyond increasing energy retention [1]. Phenomena like changes in hydrological [2] and biogeochemical cycles (particularly nitrogen's [3–5]) can lead to changes in the ecophysiology of trees, which in turn will cause modifications of plant biomass stoichiometry, changes in growth-limiting factors, and alterations of production and decomposition of organic matter. In addition, human activity has modified not only the atmosphere, but also the placement and composition of forests, either by harvesting or by planting trees in and out of their species´ natural distribution ranges. Forest species composition has also been greatly modified, usually by reducing the number of tree species to favor pure stands easier to manage, but also by increasing the number of species when new species have arrived either by abandonment of human activities or by expansion of invasive species. Collectively, all these changes have created a very complex cocktail of modified ecological factors [6]. Therefore, the collection of research works presented in this Special Issue intends to bring attention to these interactions, trying to bring better understanding about some of them.

Climate change modifications other than temperature, and particularly precipitation, will become predominantly important in semiarid regions. At some of these areas, the disruptive effects by climate change has become noticeable in tree growth patterns since

1980, such as in Chilean *Nothofagus macrocarpa* forests. Venegaz-González et al. [7] explored which climatic factor was responsible for such change. Whereas they found winter-spring precipitation as influential in all forests, only growth trends at the Andes and Coastal populations were negatively correlated with temperature, pointing out to the important effects that topography has in modulating climate change effects. The results of CO_2 fertilization analyses were controversial and unclear, in line with other reports that have shown that interactions among climate factors can make predicting tree responses to increasing CO_2 levels very complex [8].

The issue of decreasing growth rates after the 1980s has been reported also in Asia. In this issue, Zheng et al. [9] showed how *Fokienia hodginsii*, an endanger conifer, has decreased its growth, increased the frequency of missing rings, and experimented an unprecedented increase in sensitivity of ^{13}C and radial growth to drought, likely related to increasingly dry conditions. These researchers linked these negative effects to a spike in tree mortality, which may have resulted from diminished carbon fixation and water availability. As increased drought severity and frequency in southwestern sites is expected to increase in the future, the need for effective mitigation strategies to maintain this endangered tree species is becoming urgent.

Marking the 1980s as the point when general decreasing growth trends can be found worldwide is a recurrent topic in research. Adding evidence from Korea, Park et al. [10] detected such negative trend in Korean fir (*Abies koreana*) subalpine populations. These authors showed how this species is faced not only with worsening growth conditions but also with increasing competition with other species as well. As a result, it is expected that over time only a few Korean fir populations will survive on northern slopes or cool valley bottoms.

Maintaining their current distributions will be particularly challenging for trees in drought-prone areas, such as in southwestern Europe. Vizcaíno–Palomar et al. [11] studied the capacity of a widely distributed species such as *Pinus sylvestris* to become locally adapted to drought. These researchers predicted increasing tree heights for most of the studied populations by the year 2070, under the RCP 8.5 scenario, showing the capacity of this species to acclimatize to new climates. Hence, this research showed than in spite of being in the marginal areas of the species distributions, local adaptation and acclimation capacity of populations in the marginal fringes of distribution can help these populations to keep pace with climate change. Again, results by [11] highlighted the importance of analyzing, case-by-case, populations' capacities to cope with climate change.

The complexity and local dependence on how climate change will likely affect trees is a recurrent result in current research. In this special issue, Fernandez-Pérez et al. [12], also studying *Pinus sylvestris* populations in southwestern Europe, detected opposite growth trends at population level over time, depending on elevation. These authors showed how through the last 80 years, environmental conditions (likely combined with other factors) have become more adverse for growth at high altitudes, but have improved at low altitudes, reinforcing the need to study local factors such as topography, as they can modulate the impact of climate change on these forests.

The linkages between forest growth and climate change go beyond growth trends and could affect ecosystem services such as water provisioning. Rong et al. [13] explored the effects of climate change on Qinghai spruce (*Picea crassifolia*) forests in northwestern China, as they play a key role in water conservation in this dry region. These authors estimated that the warmer the climate condition is, the more area of higher suitable classification is changed to that of lower suitable classification. The reduction of suitable area could reach 13% of its current distribution (185 km^2) under the RCP 8.5 scenario. As this region is the origin of many rivers in China, water provisioning could be also impacted.

However, the issue of declining growth patterns due to climate change is not unique to semiarid sites. In fact, Gu et al. [14] focused on studied climate change effects on Masson pine (*Pinus massoniana*), the most widely distributed tree species in the subtropical wet monsoon climate regions in China. These authors reported that spring and autumn climate factors are important controls of tree growth. As future temperatures are expected to surpass those of the optimum growth threshold for Masson pine, the adaptation of this species to future climate regimes will be an important challenge due to its importance in the Chinese forest sector.

The implications of climate change on tree growth are not limited to specific locations, but they can reach global changes in the carbon cycle. For example, Zhang et al. [15] modelled the relationships between tree diameter, height and age for China's main tree species under climate change and the carbon stocks associated. Their results showed that the biomass carbon stocks of Chinese forests would increase from 7342 to 11,030 Tg C in 2013–2050, with an annual biomass carbon sink of 99.68 Tg C year^{-1}, and they indicated that the Chinese land-surface forest vegetation has an important carbon sequestration capability.

As seen in the different works presented in this special issue, climate change will have important implications at local to regional levels, and from arid to moist regions. González de Andrés [16] provides a detailed review on how climate change will be combined with the modification of global biogeochemical cycles of carbon and nitrogen, affecting forest functions at different scales, from physiology and growth of individual trees to cycling of nutrients. In this review, the author shows how, at the community level, responses to global change are modified by species interactions that may lead to competition for resources and/or relaxation due to facilitation and resource partitioning processes. The author provides evidence from literature showing how mixed forests can be more drought-resistant than pure forests, although always depending on the particular traits that the species in the mixture have. The review ends providing a discussion of the patterns and underlying mechanisms governing the relationships between diversity and different ecosystems functions, such as productivity and stability.

All things considered, this Special Issue provides readers with a collection of different studies exploring the interactions between climate change and tree growth on different continents (South America, Europe and Asia), in different biomes (semiarid Mediterranean, cool subalpine, warm subtropical), and at different scales (from local populations to sub-continental studies). These research studies join the quickly developing body of literature that is helping to understand the new challenges facing forest ecosystems in the near future, whereas the review by [16] provides a solid theoretical foundation to consolidate what is known so far. We hope readers will enjoy reading this Special Issue as much as the editors enjoyed managing it.

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