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Challenges and opportunities of the temperate forest in the context of global climate policy

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Current state and processes in temperate forests

Temperate forests have historically occupied many of the adjacent zones at lower latitudes between 25° and 50° in both hemispheres, and range from deciduous forests in areas with moist, warm summers and frosty winters (Röhrig & Ulrich 1991), to broadleaf evergreen forests in moist regions with mild, nearly frost-free winters (Ovington 1983) and sclerophyllous forests in drier regions (Figure 1). The mixed forests containing both deciduous and coniferous trees occupy intermediate areas between temperate and boreal zones. The climate of the temperate region spans a wide range of intermediate conditions that influence productivity, including low winter temperatures and low summer water availability. The principal genera include pine (Pinus), oak (Quercus), beech (Fagus), maple (Acer) and eucalypt (Eucalyptus).

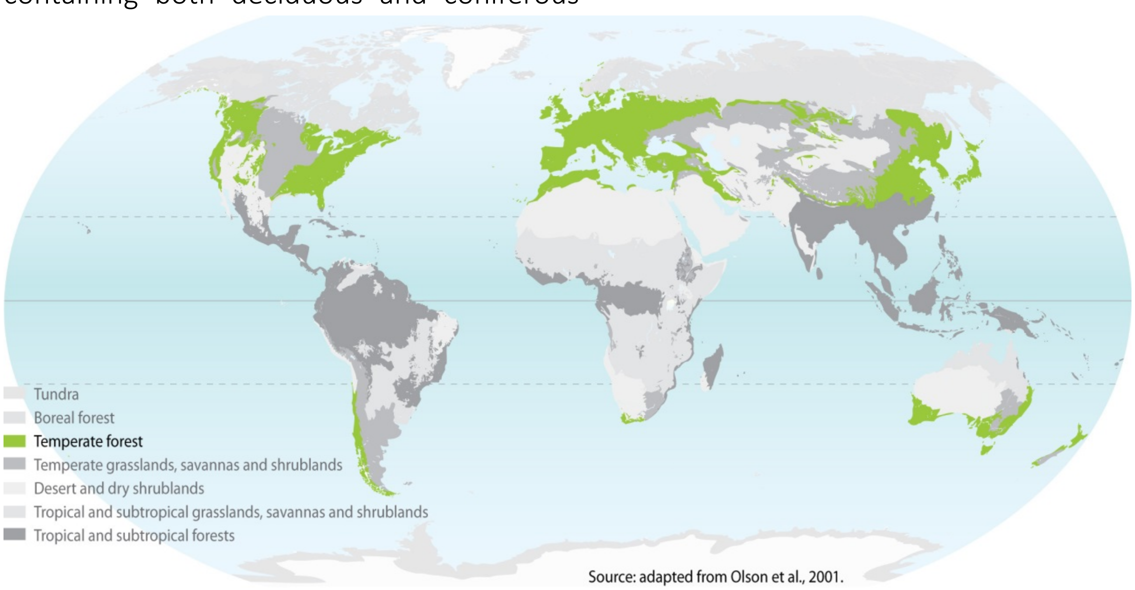

Figure 1. World temperate forest (source: GRID-Arendal). Temperate forests are typical of all European continents, the Eastern region of Asia, North America, as well as in tempered areas of South America, Australian and New Zealand.

The temperate zone has followed a historical pattern of land-use change involving a gradual reduction in forest area and density due to overexploitation and agricultural expansion, followed by a recovery of forest area and density through natural reforestation and afforestation to a level that is still lower than the pre-agricultural state (Pan *et al*., 2013). Rates of net temperate forest clearance were fairly constant at about 1 Mha per year between 1850 and 1970, and have subsequently declined to about zero. The total area of temperate forests has been reduced from 1,583 Mha in 1850 to 1,492 Mha in 1980, which caused a net carbon release (27 Gt C) (Malhi *et al*, 1999). According to the MODIS forest/woodland cover, the existing temperate forest has increased to 2,079 Mha, accounting for 27% of the total forest area (Pan *et al*., 2013). Temperate forests hold ~20% of the world's plant biomass and ~10% of terrestrial carbon (Bonan, 2008). The current forest biomass is only ~30% of what the potential would be without human use of the land for food production, fiber, and other non-forest land uses (Pan *et al*., 2013).

Temperate forests contributed 0.7±0.1 and 0.8±0.1 Pg C per year (27% and 34%) to the global C sinks in established forests for two decades (1990-1999, 2000-2007). The primary reasons for the increased C sink in temperate forests are the increasing density of biomass and a substantial increase in forest area. The U.S. forest C sink increased by 33% from the 1990s to 2000s, caused by increasing forest area; growth of existing immature forests that are still recovering from historical agriculture, grazing, harvesting; and environmental factors such as CO2 fertilization and N deposition. The European temperate forest sink was stable between 1990 to 1999 and 2000 to 2007. There was a large C sink in soil due to expansion of forests in the 1990s, but this trend slowed in the 2000s. However, the increased C sink in biomass during the second period (+17%) helped to maintain the stability of the total C sink. China's forest C sink increased by 34% between 1990 to 1999 and 2000 to 2007, with the biomass sink almost doubling, which was caused primarily by increasing areas of newly planted forests (Pan *et al*., 2011).

The net climate forcing of temperate forests is highly uncertain. Competing biogeophysical forcings from low albedo during winter and evapotranspiration during summer affect annual mean temperature. A higher albedo due to loss of forest cover could offset carbon emissions, so that the net climatic effect of temperate deforestation is negligible. On the other hand, reduced evapotranspiration due to a loss of trees could amplify expected warming. The climate benefit of temperate forests is most uncertain. Reforestation and afforestation may sequester carbon, but the albedo and evaporative forcings are moderate compared to other forests and the overall evaporative influence is unclear (Bonan, 2008).

Opportunities in temperate forests

The temperate forest cover has stabilized and even increased significantly owing to the intensive programs of reforestation, afforestation and improvement of existing forests in many temperate counties. The drivers of increasing forest cover in temperate countries include: the intensification of agriculture and agricultural overproduction resulting in set-aside policies; the loss of soil fertility; the increasing value of forests' amenity services; climate protection and watershed protection uses; and a growing public understanding of the environmental values of forests (Shvidenko *et al.* 2005). In Europe, a number of countries have developed national polices aimed at conversion of agricultural and marginal land uneconomic to farm into forest. The economically optimal land use has changed over the last century and trees have been either replanted or allowed to regenerate naturally. In China, since the 1970s the planting area has been increasing rapidly by more than 5 Mha per year on average without showing any signs of slowing even after almost four decades of continuous increase. At the beginning it was essentially government-initiated programmes that stimulated tree planting across the country in the face of the severe depletion of forests after decades of mismanagement, severe misuse and complete neglect. Growth in urban and global markets for forest products, coupled with demographic migration from rural areas into urban zones, spurred the conversion of abandoned crop fields into tree farms (Liu *et al*. 2014).

Temperate expansion across local eco-tones suggests an increase in mixed temperate-boreal forests in the near-future. Temperate forests are forecast to change in composition and shift spatially in response to climate change. Detectable responses, consistently in the directions predicted for both temperate and boreal species, indicate that summer temperature is likely an important driver of natural tree regeneration in forests across the temperate – boreal transition zone. Temperature sensitivities point toward an eventual northward shift in the regional transition zone as temperate species expand and boreal species fail to regenerate near southern range limits (Fisichelli *et al*, 2014)..

Challenges in temperate forests

While temperate forest cover has stabilized and increased, the quality of these forests is threatened by climate change, air pollution, fire, pest and disease outbreaks, continued fragmentation, and inadequate management and so on (Shvidenko *et al*, 2005).

Global climate change is expected to enhance the frequency and the severity of drought events in several regions and particularly in the Northern hemisphere (Breda et al., 2006). During the course of the 21st century, the global-average surface temperatures will likely increase by 2–4.5 °C. At the same time, there will be changes in precipitation regimes with probably larger winter rains and more severe precipitation deficit during summer. Extreme climatic events such as heat waves and drought episodes like those experienced during summer 2003 in Europe are expected to occur at increased frequencies in temperate zone. Productivity of forest ecosystems is severely constrained by water availability and droughts may induce large-scale tree decline episodes in temperate forests. Soil water shortage impacts several steps of water transfer along the soil-tree-atmosphere continuum. Drought results in lower soil water availability. Reduced water availability alters both soil-root and leaf-atmosphere interfaces and threatens the integrity of the liquid phase continuum from soil to leaves. Water and CO2 fluxes are decreased; as a consequence, tree growth is limited and individual tree survival may become problematic in case of extreme soil water depletion. Changes in water and carbon cycles due to drought have to be analyzed for different tree species and over several years to detect potential changes in carbon allocation to tree compartments and to physiological functions (respiration, growth, storage). Nitrogen nutrition and cycling are likely to be modified by drought (Gessler *et al*, 2004), and the impact of nutrient shortage under water deficit has to be quantified at various levels of site fertility and for drought-tolerant, resistant or vulnerable tree species.

Global change is likely to have a major impact on future yield modelling in forest management. The addition of several uncertainty terms will make a procedure complicated by a number of theoretical and practical limitations. Stand growth rates are already changing in a number of areas, and global change can only result in the extension and acceleration of this process. Yield modelling must take such changes into account if it is to predict future forest productivity successfully (Innes, 2004).

Air pollution has caused a continuous deterioration of forests in Europe from 1986 to 1995, with the proportion of healthy trees falling from 69% in 1988 to 39% in 1995. Results for 1995–2001 show stabilization at a high level of damage, with almost a quarter of the sample trees rated as damaged due to air pollution. Air pollution induces changes in tree physiology, phenology, and biochemical cycling. Among air pollutants affecting forest health, sulfur, nitrogen, heavy metals, and ozone are the most pervasive, although the complexity of forest decline in relation to air pollution suggests that decline in condition has been due to the combined impacts of eutrophication, acidification, and climate change. The impacts of pollution on forests are not confined to industrial countries. Although anthropogenic emissions of sulfur dioxide have recently declined in most industrial countries in Europe and North America, emissions have increased in a number of countries of Asia, Africa, and Central and South America. Emissions of nitrogen oxides due to human activities remain constant or have increased over vast regions.

Forest fires have long been recognized as a paramount issue for the resilience of temperate forests. In May 1987, a megafire in the Daxing'anling region of northeast China burned 1.33 Mha of forest and resulted in 213 deaths. Even though the Chinese government has increased its investment in fire control agencies and fire prevention infrastructure since the late 1980s, the country's average annual burned area from 2000 to 2009 was 333,796 ha, of which 138 712 ha (42%) were in forests. Of the yearly forest fires within China, 52% occur in the south, followed by 37% in the southwest, 6% in the northwest, and 4% in the northeast and Inner Mongolia. More than 98% of forest fires were estimated to be caused by human activities between 2001 and 2010, while global warming has already exerted a major impact on forest fires (Zhao et al. 2009). Recently, there has been a surge of extremely destructive fires with corresponding social disruptions and substantial economic costs. Over the last decade, annual wildfire suppression costs on US federal lands and Canada has exceeded $1.7B US dollars and $1B US dollars, respectively. When all components are considered, including preparedness/ suppression costs and economic losses, these total costs are substantially higher. In Australia, total wildfire costs were estimated at nearly $9.4B US dollars or 1.3% of their GDP in 2005. Therefore, the driving factors of contemporary wildfire activity changes must be understood to ensure that wildfires are effectively managed to promote healthy ecosystems while minimizing negative socio-economic impacts (Jully, *et al,* 2015).

Although disturbances such as fire and native insects can contribute to natural dynamics of forest health, exceptional droughts, directly and in combination with other disturbance factors, are pushing some temperate forests beyond thresholds of sustainability. Interactions between increasing temperatures, drought, native insects and pathogens, and unusually severe wildfires are resulting in forest mortality beyond the levels of 20th-century experience. Additional anthropogenic stressors, such as atmospheric pollution and invasive species, further weaken trees in some regions. Although continuing climate change will likely drive many areas of temperate forest toward large-scale transformations, and changes are inevitable, the actions we take now in temperate forests can ease and guide transitions, diminishing effects on forest ecosystems and the human societies depending on their services.

Fragmentation of remaining areas of forest is a common side-effect of logging and clearance as temperate forests and woodlands are often located in areas with long histories of human land use and land use change. In areas of forest that are close to cleared areas, there is frequently low level use of forest wood, and even in protected areas there appears to be a loss of biomass subsequent to fragmentation, perhaps driven by changes in microclimate amongst other factors. Fragmentation can cause 'edge effects' whereby trees are more exposed to increased solar radiation, wind, temperature fluctuations and soil drying than in the forest interior, and larger scale climatic patterns or events may exacerbate these effects. Contrasting landscape characteristics, such as patch size, will affect forest sensitivity to climate, and different species will be impacted differently. These processes are hard to assess and quantify, and so are rarely included in estimates of carbon release by forest clearance (Malhi *et al*, 1999).

The future of temperate forests and their climate services is highly uncertain. The present carbon sink in eastern United States forests is likely to decline as recovering forests mature, and these forests face uncertain pressure from climate change, atmospheric CO2 increase, and anthropogenic nitrogen deposition. Change in the balance between deciduous and evergreen trees is likely in the future. The trend over the past several decades has been toward farm abandonment, reforestation, and woody encroachment from fire suppression, but meeting the needs of a growing global population for forest products, bioenergy and other demands could place greater pressures on these temperate forests.

Summary in three sentences

- The temperate forests have followed a pattern from over exploitation to recovery and increase stabiliy, contributing to the society with forest products and ecosystem services including carbon sequestration.
- The quality of the temperate forests is threatened by climate change, and – in some large regions - by air pollution, fire, pest and disease outbreaks, continued fragmentation, and inadequate management and so on.
- Scientific research and management actions are needed and can be conducted in temperate forests to guide transitions, recognizing the multitude of forest influences, their long-term effectiveness and sustainability in a changing climate, diminishing effects to forest ecosystems and human societies.

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