Question 5

To manage or not to manage – how can we support forests to mitigate climate change and adapt to its impacts?

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Forests are natural systems that remove carbon dioxide from the atmosphere via photosynthesis, and store carbon in biomass. Part of this carbon is transferred into soils through litterfall and tree mortality. In managed forests, part of the carbon (mainly in tree stems and major branches) may be extracted from the forest during harvest for material or energy use. If the wood is used for energy purposes, the carbon stored will be released when the wood is burned and if the wood is used for material use, the carbon is stored in wood products and released at the end of its life. In addition to carbon storage in forest ecosystems and in wood products, using wood can provide climate benefits by avoiding or reducing fossil GHG emissions if they replace products or fuels that emit more greenhouse gases during their production, use and disposal (IPCC, 2018).

Several measures can be taken to strengthen the role of forests and forestry in climate change mitigation. Through the creation of new forests, afforestation leads to the new development of forest carbon stocks and sinks. Deforestation and forest degradation are major sources of greenhouse gas emissions and avoiding or reducing these lowers greenhouse emissions to the atmosphere. Forest management can maintain or enhance carbon stocks and sinks in forest biomass and soil. In addition, long-lived wood products (e.g. construction materials) store carbon and the use of wood products can substitute for materials (e.g. concrete, steel and glass) that are typically associated with more emissions (Leskinen et al., 2018) (see also **Question 11**). Forests and forestry thus play a key role in climate change mitigation.

Forest management is one strategy to mitigate climate change. Forest management can cover a broad spectrum of approaches, ranging from a passive, or conservation-oriented approach to an active, production-oriented approach. In the former, forest management interventions may be limited or even absent with the aim to store carbon within forest ecosystems (i.e. in biomass and soil) through natural processes. In the latter, management may be active to strengthen carbon storage in forest ecosystems (e.g. through tree species selection, breeding, soil cultivation, fertilization, tending, thinning, harvest regimes, etc), or to strengthen carbon storage in forest ecosystems and products and avoiding emissions through substitution effects. A key question concerns which strategy to follow: do forests left unmanaged to store carbon in biomass and soil provide larger CO_2 emission reductions than forests kept under forest management for production of wood that can substitute non-renewable, greenhouse gas intensive materials and fossil fuels?

Several scientific studies have been conducted to compare the overall carbon effects of managed forests with production of bioenergy and/or products to unmanaged forests, including energy and/or material substitution effects [e.g., Holtsmark, 2013; Holtsmark, 2012; Cherubini et al., 2012; Taeroe et al., 2017; Schulze et al., 20202). The results from such studies reflect different views and approaches to tackle the question and their results may appear contradictory (Berndes et al., 2016). A key factor to be considered is the system that is analyzed: is the forest an unmanaged forest which is brought under active management, or is the forest actively managed and management is ceased? Another important factor is the scope of the analysis; is the analysis focusing on the local level, or is a landscape or larger-scale analysis considered?

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The comparison of the carbon effects of managed forests and unmanaged forests is generally found to be affected by the assumed growth rate and dynamics of both unmanaged and managed forests, as well as (in the case of managed forests), the type of forest management applied, the type of wood products that are produced and substituted and the assumed production technologies and conversion efficiencies of these products (see also Berndes et al, 2016). It is also essential to consider not only the consequences at the local level; stopping the active management of forests, including wood production, may lead to gains in carbon storage in forest ecosystems at one location, but these gains may be offset through international trade by imports of forest products causing deforestation or degradation elsewhere (Kastner et al., 2011; Pendrill et al., 2019a; Pendrill et al., 2019b).

Furthermore, reduced forest resource utilization may result in increased use of competing materials with often larger carbon footprints. Finally, in addition to carbon implciations, it is also important to consider biophysical climate impacts such as albedo, surface roughness, emissions of biogenic volatile organic compounds, and transpiration (Astrup et al., 2018; Luyssaert et al., 2018; Kalliokoski et al., 2020), although these latter impacts are still not well understood. A comprehensive, holistic evaluation is therefore warranted to understand the full consequences of ceasing active management.

Europe's forests are almost all managed, although management intensity varies across regions and between forest owners (Levers et al., 2014). The comparison of managed and unmanaged systems is hampered by limited information on the natural dynamics (growth, mortality, disturbances) of unmanaged forests in Europe. To illustrate, the known, remaining primary forests (i.e. naturally regenerated forests of native species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed) in Europe cover only 0.7% (1.4 million ha in 32 countries) of Europe's forest area and they are not representative for all forest types (Sabatini et al., 2018; Sabatini et al., 2020). Similarly, the natural dynamics that would occur in a transition from a managed to an unmanaged system are also not well understood.

As outlined in the answer to **question 4**, Europe's forests have been affected by climate change and this is expected to continue in the future by productivity changes, tree species suitability and extreme events and disturbances. Especially in a transition from a managed to an unmanaged forest, it is unclear how ceasing forest management would affect the development of the forests and their carbon balances under climate change. Furthermore, the present rate and magnitude of climate change exceeds the speed of natural tree species migration and their capacity to adapt to the changing conditions. Ceasing management would limit the possibility to strengthen the resilience of forests to climate change through adaptive forest management. Of particular importance is pro-active disturbance management which enables the prevention or at least the mitigation of disturbance related emissions.

To strengthen the contribution of forests and forestry to climate change mitigation, as well as the resilience of forests to climate change, the best strategy will therefore be a mix of measures. Such measures should consider long-term carbon storage in forest ecosystems, wood products and through substitution, considering regional conditions. Such measures could include (Nabuurs et al., 2013; Nabuurs et al., 2017) (i) conserving old-growth forests with high carbon-stocks not at a high risk of disturbance, and allowing them to turn into naturally developing forest; (ii) replacing mature stands that are susceptible to drought and bark beetles, with more climate-adapted species; (iii) mitigating disturbance risks in storm or fire-prone forest areas through e.g. targeted management of species mixtures, regular thinning and reduction of flammable biomass; (iv) increasing the use of wood in construction and other long-living wood products.

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