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INTRODUCTION

Water and carbon in forests: challenges for forest management under the pressures of climate change

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Background

Forests are essential for the regulation of both water and carbon cycles at all scales, ranging from tree and plot, to landscape and regional scales and the global scale. Climatic and other environmental changes and different forest management options affect forest growth and the concomitant water redistribution between tree, stand and atmosphere; the changes also affect carbon allocation and distribution (Gallardo Lancho 2000).

The papers included in this special issue are a representative selection of the contributions presented at the International Conference entitled "Managed Forests in Future Landscapes: Implications for Water and Carbon Cycles," which was the final meeting of COST action FP 0601 "Forest Management and the Water Cycle (FORMAN)," co-organized by IUFRO Working Party 8.01.04 "Water Supply and Quality" (IUFRO = International Union of Forestry Research Organizations). The meeting was held on May 8 to 11, 2011, in Santiago de Compostela (NW Spain), a World Heritage City (UNESCO).

Previous meetings in Germany, Greece, Austria, Finland, Israel and Turkey provided information about Central European, boreal and Mediterranean forests. At the final conference, the focus was on Atlantic forests. The area is subjected to particular problems, such as the degradation that occurs after wildfires or as a result of intensive management of fast-growing forest plantations. Numerous agricultural reforestation projects are also being carried out in the area. The opportunities for C capture in an abandoned mining area were also discussed. Complex interactions between human activities and forests are creating future landscapes, as discussed by three world specialists: Prof. Dr. Fernando Valladares (Spanish National Research Council (CSIC)), Prof. Dr. Jim Burger (Virginia Polytechnic Institute and State University, USA) and Prof. Dr. Irina Kurganova (Soil Science Institute, Moscow, Russia).

Transfer of knowledge to managers and society is also important, and a round table discussion involving different stakeholders involved in forest management, such as the European Forest Institute, FAO and the Silviculturist Association, was also organized as part of the final COST action conference. The session was led by Mr. Inazio Martínez Arano, executive president of the Union of Silviculturists of Southern Europe, and Dr. Douglas Godbold from Bangor University, United Kingdom.

A total of 157 contributions were presented by over 150 participants from more than 30 countries in Europe, America and Asia. Forty-eight of the participants were early-stage researchers. The contributions provided a broad overview of the complex mechanisms involved in water and carbon cycles in forests. In particular, the effects of climate change, land abandonment, reclamation of degraded sites for the prevention of environmental risks and the

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climate change mitigation potential of forests were discussed in the keynote and contributed papers. The conference contributed to the following: (a) presenting new information about soil–water relations in forest systems; (b) identifying topics of common interest and formulation of firm proposals for collaborations between research groups; (c) exchange, between researchers and managers, of recommendations for good practice in relation to sustainable forest management; (d) formulation of proposals that support the definition of collaborative policies, incentives and effective tools for sustainable forest management.

Changing environmental conditions and forest management strategies

The topic of the conference refers to the important parallel changes in environmental conditions and forest management strategies around the globe. In many parts of the world, including Europe, most forestry systems are managed more or less intensively in order to provide products and services, with direct or indirect benefits. Two of the most important additional environmental benefits of forestry systems are as follows: (a) the provision of water and regulation of water quality and (b) the contribution to the global carbon balance.

As regards management, intervention is minimal in certain areas, such as mountains and hillsides, while in other areas, forest systems are managed in a similar way to traditional single crop farming systems. The area of forested land has increased greatly in different European countries in recent years as a consequence of the implementation of conservation measures (Eurostat 2011) and the rehabilitation of degraded land (e.g., mines and quarries; Zipper et al. 2011). This increase is continuing as a result of reforestation of abandoned agricultural land, often after depopulation of the areas (Kurganova et al. 2010). New areas of exploitation, such as biomass for energy generation, are also important.

Reforestation or rehabilitation of degraded land and conversion to forest systems usually lead to better hydrological regulation and improved water quality. This also leads to a parallel increase in the capacity of the system in terms of soil and biomass carbon sequestration (Bredemeier et al. 2011).

Although the contribution of forests to flood control and cleaning of air masses is of great importance, forest research is increasingly focused on mitigation of climate change, as forests can respond to and help reduce excessive CO_2 emissions to the atmosphere (e.g., Paivinen et al. 2012).

Forests also ensure sustainable water quality. Water is one of the most important resources for life on earth, along with solar radiation. Together these two factors determine the climate at any given place on earth, which in turn determines the natural potential productivity of ecosystems. With respect to water resources, the importance of forests outweighs their relative proportions, since forested landscapes are the preferred sources for the generation, storage and export of drinking water supplies for human populations (Schleppi 2011).

Forests are an essential part of European landscapes. They cover about a third of the land area in Europe (27 % in Central, 32 % in southern and 50 % in Northern Europe, Eurostat 2011). Almost all forest land in Europe has been more or less intensively managed, and therefore, strictly “natural forest” is scarce. Although this is not widely known by the general public, forests are nevertheless highly valued for their relative similarity to natural ecosystems and for the various services that they provide (Pichler et al. 2011). They are the richest ecosystems in pool and fluxes, hence their high potential for environmental protection. Water regulation and supply from forest soils and aquifers are some of the most important of such services. Forest ecosystems supply high-quality drinking water and process water for the human population and also safeguard against both flooding and erosion by retaining water and thus delaying and mitigating peak flows.

The above-mentioned aspects are very important in the humid Atlantic region, where the high demand for wood is leading to an increase in numbers of intensively managed plantations (Ben-Hur et al. 2011). Although these systems provide opportunities for improving the water and carbon balance (biomass for energy, restoration of degraded areas, afforestation of marginal agricultural soils), knowledge-based management systems must be implemented to avoid erosion and other problems such as decreased biodiversity (Paillet et al. 2010).

The protective function of forests with respect to water quality and water-related hazards is potentially at risk under the changing climate and changing land management practices. The water budgets in forest ecosystems depend greatly on climate and forest structure. The latter is determined by different management measures applied in the forestry sector, such as selection of tree species, stand structure and density management, harvesting methods. Both climate and forest management practices are expected to change in the coming decades. The intention in many European countries is to establish forest stands that are more similar to the potential natural forest vegetation. This will generally involve increasing the area of broadleaved and mixed stands while reducing the area of monospecific, “artificial” conifer plantations that have been favored in many European countries. However, in some European countries, there are plans for widespread (re)afforestation, partly with monocultures; such plans mainly involve countries with large areas of very poor soils, recently reforested with conifers.

All of these different trends must be considered when assessing the overall forest–water–carbon interactions in Europe. Changing forest management practices and global changes are together leading to an unprecedented set of management challenges in regard to European forests. The papers in this special issue, most of which are regional case studies, highlight some of these challenges.

The papers included in this special issue

This special issue provides excellent examples of how forest management affects the carbon cycle under a wide range of environments and conditions. Changes in carbon stocks in soils and biomass have been evaluated in Mediterranean, continental, boreal and Atlantic forests. These case studies cover a wide range of systems and address important challenges in current forest management, such as afforestation–deforestation, agroforestry systems, intensive forest management and mountainous forests.

Álvarez Arteaga et al. (2012) examined soil organic matter in mountain cloud forest in Mexico. In accordance with theoretical considerations, the soil organic carbon (SOC) pool decreases with altitude, as does biomass production in forest ecosystems. There is usually a well-defined depth profile of SOC, with strong accumulation in the superficial layer and a rapid exponential decline in depth. Spodic soil horizons can modify the depth profile.

The role of agroforestry systems in the Mediterranean environment is considered by González González et al. (2012). These authors have studied soil carbon stocks and solution chemistry in a large number of *Quercus ilex* stands managed in agroforestry systems under different regimes. One of the most important aspects arising from their studies is the dependence of SOC storage on tree density and, secondarily, on soil properties.

The changes brought about after forest clearing are discussed in two distinct environments. The study by Ahmed et al. (2012) aimed to fill a knowledge gap by obtaining information about SOC stocks in karst areas worldwide. These authors analyzed SOC stocks in karstic soils under centuries-long agroforestry management regimes, by using an electrical resistivity tomography to measure stoniness. They found that the SOC content is significantly lower in cropland than in both forest land and pasture land.

Fernández et al. (2012) examined carbon fluxes and SOM compounds, and in particular, they measured CO_2 emissions from pastures established after forest clearing in northwestern Spain. After only 5 years, deforestation and conversion to pasture led to a general decrease in soil CO_2 emissions with reduced seasonal fluctuations. A new long-term C input/output equilibrium appears to have been established. However, the SOC retention capacity remains limited in comparison with that of the original forest ecosystem.

Afforestation is addressed in two studies. Pérez-Cruzado et al. (2012) investigated the carbon balance in fast-growing forest plantations (*Eucalyptus globulus*, *Eucalyptus nitens* and *Pinus radiata*) established on former pasture land. These authors applied a modeling approach to evaluate the effects of different management regimes for the above-mentioned fast-growing species in southern temperate Europe in relation to mitigating climate change. On the other hand, Kulakova (2012) investigated the impact of tree species in plantations established under virgin steppe vegetation on the formation of carbon and nitrogen stocks in soils in an arid environment. The selection of tree species determined the carbon and nitrogen stocks in soils. The organic carbon and nitrogen stocks were higher in the litter of all man-made forest plantations than in the virgin steppe soils, whereas in the 5- to 40-cm soil layer, the C and N pools were lower in the former than in the latter.

With the paper by Novák and Kňava (2012), the focus within the sequence of articles shifts from a predominantly carbon to a predominantly water perspective. These authors believe that stoniness greatly modifies the hydrological characteristics of a forest site and that this aspect is often overlooked. In particular, a combination of dense canopy and stony soil may lead to critical water supply situations for the forest and to very low seepage and discharge rates.

Kurjak et al. (2012) studied the physiological responses of irrigated and non-irrigated Norway spruce trees during a natural summer drought period; one group of spruce trees was irrigated, while the second group was kept under the natural soil drought. It appears that leaf water potential plays only a minor role in early stomata regulation of Norway spruce. Almost complete stomata closure, even of the irrigated trees, was caused by the increase in vapor pressure deficit of the air above a value of approximately −1.5 kPa.

Finally, De Figueirido et al. (2012) examined the effects of intensive site preparation, involving deep soil perturbation, on soil loss and runoff in northeastern Portugal. An extensive network of runoff erosion plots was established in order to assess eight different types of management carried out in sites with different topographies. Soil loss and runoff tend to increase with tillage intensity. The maximum enhancement factors against the undisturbed control (abandoned field) were 7.0 for runoff and 12 for soil loss (water erosion).

Together these case studies clearly illustrate and quantify the challenges for carbon and water management in an interesting diversity of forest ecosystems.

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