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Review

Effects of forest management on biodiversity in temperate deciduous forests: An overview based on Central European beech forests

E.D. Schulze

Max-Planck Institute of Biogeochemistry, Box 100164, 07701 Jena, Germany

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ABSTRACT

This overview of relationships between biodiversity and management focuses on Central European *Fagus* forests. Present management and conservation activities are embedded in the geographic and historic background of Central European forest flora, including endangered, protected, and plant species for which Germany has taken special responsibility to ensure their future survival. Managed and unmanaged forests are compared with respect to plants and other organisms. Based on the floristic background, management for climate change and consequences of conservation on a global ecological footprint will be discussed.

The Central European tree flora contains only about 7% of the tree diversity of East Asia. Only a few genera re-migrated to Central Europe after the Pleistocene, while others were lost during the Pleistocene, e.g. the genus *Pseudotsuga*.

In this study the forest flora is characterized by specialized plant species that only grow in forests. These forest specialists contribute only 10% of the plant species of the total German flora. This fraction is even less (4–5%) for Romania which is generally regarded as a region with close to "natural" forest conditions. Also, the forest flora of Germany and Romania contains fewer apomictic and hybrid plant species than the non-forest flora. No forest plant species have gone extinct in Germany in the past 250 years, which is the time since the first floristic documentation of a plant species that was lost in Thuringia, despite intense forest use including changes in dominant tree species.

With respect to the Natura 2000 goals of maintaining species diversity of Europe, the deciduous forest, as managed by rotation forestry, contain more protected and endangered species, and species for which Germany has taken responsibility than protected forest. Forests managed with permanent forest cover (so-called "management close-to-nature") contain fewer plant species than age-class (rotation) forestry. The abundance of dead wood-fungi and of soil bacteria is higher in rotation forest than in protected forests. For the initial phase of decay, a dead wood experiment identified two important tree species, *Carpinus betulus* and *Picea abies*, as the most preferred tree species for xylobionts. *Carpinus* has the most diverse fungal flora among all wood types and is a typical species for managed forests.

The Natura 2000 habitat types were defined by plant species, but the assessment of ecosystem health is based on bird species in Central Europe. A time series extending from 1927 until 2015 indicates that most non-migratory forest bird species show an increasing abundance since 1970. Adding migrating and rare bird species populations resulted in constant average abundances since 1970. There is no evidence that sustainable forest management has led to decreased biodiversity in Central Europe. In view of climate change and increasing presence of tree diseases, Europe should avoid enlarging its ecological footprint by taking Central European forests out of management.

1. Introduction

It is generally accepted that biodiversity is in decline, and it has been proposed that biodiversity can only be maintained through conservation of specific ecosystems or of larger land areas (Global Biodiversity Assessment, 1995; Pimm, Jenkins, & Abell, 2014; WBGU, 2001). However, biodiversity is not equally distributed across the globe. The highest plant species numbers are found in the humid tropics and subtropics, and species numbers strongly decline towards the temperate and polar zones. Along this gradient about 35 hot spots of plant diversity have been identified as regions with high numbers of endemic species and rapidly changing land use (Mittermeier, Turner,

E-mail address: dschulze@bgc-jena.mpg.de.

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Larsen, Brooks, & Gascon, 2011). It is quite clear that major efforts are needed to maintain genetic resources in these regions (Hilger et al., 2015a, 2015b). In this context Central Europe is not a hot spot of diversity, whereas the Mediterranean Basin is a hotspot linked to the Caucasus and Irano-Anatolian regions, and thus connecting to the Mountains of Central Asia including the Himalaya and merging into the Mountains of Southwest China (see also Akhemetiev and Zaporozhets, 2014). The global map of hot spots should be a baseline for global conservation efforts. In Central Europe forest biodiversity is closely linked to human activities (Küster, 1998).

In contrast to this global knowledge, the German "Strategy for Biodiversity" aims at taking 5% of the forest land out of management (Nationale Strategie zur Biologischen Vielfalt, 2008) since "forestry" is regarded as the second most important factor endangering species after agriculture (BfN, 2015). In addition to taking forests out of management for conservation, a certification by the Forest Stewardship Council (FSC) is recommended for managed public forests, which should result in a further 10% of unmanaged land as a baseline for "natural" development and in the identification of 10 habitat trees ha^{-1}. Additionally, there are restrictions on management, despite all observational and experimental knowledge about biodiversity of re-wilding forests. The main review of the past that compared unmanaged with managed forest sites in Europe (Paillet, Bergès, & Hjältèn, 2010) concluded that age class (rotation) forestry does not differ from unmanaged forest with respect to species richness of major groups of organisms (see Paillet, Table 4). Individual organismic groups had higher species richness in unmanaged forest (see Paillet, Table 2) because of the unequal distribution of study plots and due to merging age class management with "permanent forest cover", a methodology that resulted in an apparent decline of species richness under management.

In order to further investigate the effects of management on biodiversity, a large scale observational study was initiated in Germany in 2008, where organismic diversity was investigated in southern, central and northern Germany, comparing in each region unmanaged forests with different types of managed forest using experimental plots that are part of a grid-based inventory (Fischer et al., 2010). The investigation is centered on *Fagus* forests, which are a major focus of the European Habitats Directive (http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:01992L0043-20070101, accessed 18.07.17) in which 12 *Fagus*-habitat types have been listed to be of European interest (European Commission, 2007). In addition, *Fagus sylvatica* is a UNESCO cultural heritage species (whc.unesco.org/en/list/1133/documents, accessed 18.07.17). At present, *Fagus* forests make up only about 15% of the actual forest cover in Germany (1.7 Mill ha, http://bwi.info/start.aspx, accessed 18.07.17; Grossmann, 2012) even though they could cover about 60% of the area (www.EUFORGEN.org, accessed 18.07.17). The area of *Fagus* in Germany is 20% smaller than the area of *Fagus* in Romania (2.1 Mill ha, http://roifn.ro/site/rezultate-ifn-1/, accessed 18.07.17). A large fraction of the potential distribution of *Fagus* in Germany was converted into coniferous forest in the past century. Despite the suggested importance of *Fagus* forests in the Habitats Directive, Central European *Fagus* forests contain only one out of 46 forest plant species of the Annex II plant list (http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:01992L0043-20070101).

In the following, data from the German biodiversity-management project will be reviewed in the context of the floral history of forests in Central Europe and of future climate change. I am aware that this analysis is valid only for sustainable forest management of deciduous forests, and it cannot be expanded to exploitation forestry in other regions of the world. The focus will mainly be on plants, because plants were the basis for distinguishing the habitat-types in the Habitats Directive. I will present data on other organisms as they are available, extending the analysis beyond the project boundaries. All study plots were located inside Natura 2000 sites. It is the aim of this study to show the multiple facets of effects of management and conservation, and to draw conclusions about future development for maintaining diversity in Central Europe's Forests.

Table 1
Number of tree species in the temperate climate of Central Europe, Eastern North America and East Asia (Schulze et al., 2015).

Number of tree species	Central Europe	Eastern North America	Northeastern Asia
Broad leaved	55	203	733
Coniferous	8	33	94
Total	63	236	827

2. The floral history of central europe

Biodiversity of Central European forests can only be discussed in a historic context, because the flora was impoverished during the Pleistocene, and all forest tree species of Europe have a post-glacial migratory background. In a comparison to the tree diversity of temperate deciduous forests elsewhere in the Northern Hemisphere (Schulze et al., 2015), East Asia is by far the most diverse broad-leaved forest region of the Northern Hemisphere, containing almost 4 times as many tree species as North America and more than 10 times as many tree species as temperate Europe. The differences are larger than possible effects of taxonomic nomenclature (e.g. a tendency to split genera into many species exists in East Asia, contrasting with a tendency to lump species in North America) (Table 1).

In Europe, the main genetic source for forests is East Asia. Many of the temperate zone tree species migrated from East Asia via the Caucasus and invaded Europe via the Balkans in the Cenozoic. Examples include the genera *Fagus* (Denk and Grimm, 2009) and *Pseudotsuga* (Kunzmann, 2014; Yabe, 2011; Fig. 1). Both genera evolved in Northwestern North America (Oregon) and migrated to Japan and China during the course of the Cenozoic. *Fagus* and *Pseudotsuga* reached the Caucasus and Europe from China via the Central Asian Mountains. In the Cenozoic, there were 4 *Fagus* species and 3 *Pseudotsuga* species growing in Central Europe forming mixed deciduous-coniferous forest stands.

The ancestor of the contemporary *Fagus sylvatica* is the Eocene *Fagus castaneifolia* (Fig. 2A) which gave rise to *Fagus gussonii* in the Oligocene, a species that went extinct about 5 Mill years ago. *Fagus castaneifolia* then split into the contemporary *Fagus crenata* and *Fagus haidingeri* about 23 Mill years ago, and it is *Fagus haidingeri* which split into the contemporary *Fagus sylvatica* and *Fagus orientalis* only about 9 Mill years ago (Grímsson, Grimm, Zetter, & Denk, 2016;Renner, Grimm, Kapli, & Denk, 2016). In fact, *Fagus sylvatica* and *F. orientalis* are the youngest of all contemporary *Fagus* species. *Fagus lucida* and *F. grandifolia* are evolutionarily much older species (38 and 45 Mill years old respectively). After the last glaciation, *Fagus sylvatica* invaded Northern Europe from Italy and possibly from refugee regions in Southern and Southeastern Europe (Magri, 2008), and the migration of *Fagus sylvatica* into northern Europe is closely related to the spread of agriculture (Endrodi and Gyulai, 2000).

The history of *Pseudotsuga* is very similar to that of *Fagus*. The contemporary *Pseudotsuga sinensis* has cones that are similar to those of European *P. jechorekiae* and *P. loehrii* in Cenozoic Europe (Kunzmann, 2014; Fig. 2), even though the cones became larger in contemporary *P. sinensis*. In contrast to *Fagus*, *Pseudotsuga* did not reach the Caucasus and Europe after the Pleistocene, despite its presence in Europe in the Miocene. Thus, *Pseudotsuga* may be regarded as a Palaeo-neophyte (Schulze et al., 2015) in the modern forest flora of Europe. It is a genus that was part of the European flora in the late Cenozoic under similar climatic conditions as those that exist today. Only by chance, this genus did not reach Europe again. There is no science basis to reject cultivation of *Pseudotsuga* by nature conservation.

Fig. 2 bottom: Cones of the European Cenozoic *Pseudotsuga*