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Invited review

Root reinforcement dynamics of European coppice woodlands and their effect on shallow landslides: A review

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ABSTRACT

In European mountain regions, forests play an important role in the mitigation of risk due to natural hazards such as landslides, rockfalls, floods and avalanches.
Conifer species usually provide a protective effect at higher altitude, while at lower altitudes broadleaf species are dominant. These forests are or were often managed as coppice systems.
The high stem density of coppice stands, their rapid growth and the permanence of root systems in the soil can be considered as assets in terms of protective function. However, these considerations are poorly researched and there is generally a lack of studies investigating the suitability of coppice as protection forests. The issue is relevant, considering that many coppice stands in mountain regions have become uneconomic and are now abandoned and overaged. Whether and how to manage these forests stands is a key question for practitioners.
In this contribution we analyze the implications of coppice management for slope stability and in particular to mitigate shallow landslides, focusing on root reinforcement, the main mechanism by which vegetation can reinforce slopes.
We review available studies concerning root distribution and dynamics in coppice stands to formulate hypotheses about their contribution in terms of root reinforcement. Finally we highlight the lacks of knowledge and the further steps needed to properly evaluate the effectiveness of the coppices in protecting against shallow landslides.

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1. Introduction

More than 20% of European forests directly protect soil, improve water quality or provide other ecosystem services, while 2% (7% including the Russian Federation) are specifically designated to protect infrastructure (MCPFE, Ministerial Conference on the Protection of Forests in Europe, 2015). The importance of these functions is reflected in European forest policies, where most countries focus on further maintaining and enhancing the role of forests to prevent soil erosion and protect water quality.

In mountain regions, forests play an important role in mitigating the risks of natural hazards such as landslides, rockfalls, floods and avalanches. In these areas, this specific ecosystem service is well known and integrated into risk management, and the percentage of protection forest cover reaches values up to 50% of the total forested area, as for instance in Switzerland (Losey and Wehrli, 2013). In Europe, about 3.3 million hectares of forest provide a direct protection against natural hazards (MCPFE, 2015).

The continuity and sustainability of forest protective functions strongly depends on the type of management and the dynamics of forest regeneration. Natural disturbances such as fires, storms, insect pests and diseases (Schelhaas et al., 2003), besides timber harvesting, can cause temporal reductions or even total elimination of the protective effect, exacerbating the magnitude and intensity of natural hazards (Conedera et al., 2003; Feistl et al., 2015; Maringer et al., 2016). Similarly, soil erosion risk may increase. Soil loss, resulting from forest harvesting, can become an issue at slope gradients above 8–9° and increases significantly above 20°, when major landslides and debris flows are likely to occur (Borrellia et al., 2016). Construction of forest roads may exacerbate the occurrence of shallow landslides and surface erosion (Sidle and Ochiai, 2006). These processes directly influence water quality increasing the sediment transported in suspension and the intensity of related natural hazards at the catchment scale such as floods and debris flows.

By adopting an appropriate silviculture (e.g. Frehner et al., 2005; Berretti et al., 2006), protection forests can permanently reduce natural hazards' damage to human life and property, although in cases of extreme risk trees may have to be supplemented or replaced by civil engineering solutions (Dorren et al., 2005; Dorren et al., 2007). As a general rule, in European mountains, coniferous forest species such as Norway spruce (*Picea abies* (L.) H. Karst), silver fir (*Abies alba* Mill.) and European larch (*Larix decidua* Mill.) provide a protective effect at higher altitudes, whereas broadleaved species are dominant at lower altitudes, even if in many European forests the lower forests belt were replaced by Norway spruce monocultures (Lässig and Močalov, 2000).

In different European areas these broadleaved forests were often managed as coppice systems. Coppice forests are located mainly in the central-southern parts of Europe (Fig. 1). Coppice woodlands cover about 6.8 million ha in France, 5.7 million ha in Turkey, 3.3 million ha in Italy, over 3 million ha in Spain, 1.6 million ha in Greece, 1.8 million ha in Bulgaria,

1.4 million ha in Serbia and Montenegro, 0.84 million ha in Bosnia and Herzegovina, 0.56 million ha in Republic of Macedonia, 0.5 million ha in Hungary, 0.54 million ha in Croatia, 0.4 million ha in Albania, and 0.25 million ha in Romania (Nicolescu et al., 2014).

Coppice management has a long tradition and was developed in numerous forms (Piussi, 1994; Nyland, 2007; Smith et al., 1997). The most common coppice species in Europe are European beech (*Fagus sylvatica* L.), oaks (*Quercus* spp.), sweet chestnut (*Castanea sativa* Mill.), limes (*Tilia* spp.), maples (*Acer* spp.), ash (*Fraxinus* spp.), hazel (*Corylus avellana* L.), whitebeam and wild service tree (*Sorbus* spp.), hornbeam (*Carpinus betulus* L.), hop hornbeam (*Ostrya carpinifolia* Scop.), and black locust (*Robinia pseudoacacia* L.) (Jancke et al., 2009). Additionally, species that form Mediterranean scrub, such as *Quercus ilex* L., are often managed as a coppice.

In terms of their protective function, the high stem densities of coppice stands can be considered advantageous (Gerber and Elsener, 1998). Additionally, their rapid re-growth from stools results in the formation of a complete cover within a few years. Moreover, part of the root system remains alive or regenerates itself rapidly after cutting. However, these considerations are poorly researched and there is a lack of studies investigating the suitability of coppices as protection forests.

The issue is particularly relevant because nowadays in mountain areas many coppice stands are uneconomic and are now abandoned and overaged. This problem is particularly relevant in mountainous areas in the southern side of the Alps. Overaged coppice stools have oversized aerial biomass and limited root systems (Conedera et al., 2010), which in time may lead to instability and uprooting (Vogt et al., 2006). Fallen and uprooted trees may then be transported into erosion gullies, torrents and rivers by landslides and windthrow events, intensifying the debris flows hazard. In some cases it is even argued that the weight of the vegetation may trigger shallow landslides (Motta, 2016); however, it has been demonstrated that this effect is rarely relevant for slope stability. Trees have the effect of increasing the surcharge, and hence the shearing stresses, on a slope, but at the same time they also increase the normal stresses, with a stabilizing effect. The overall positive or negative effect on the stability depends on the slope steepness: on very steep slopes this can be a problem; however root strength can often offset any increase in shearing stress (Selby, 1993). It must be also considered that a whole forest on a slope represents a relatively small surcharge when compared to the soil mantle and other weight factors: for this reason it is not seen as having a significant effect on slope stability (Stokes et al., 2008).

Whether and how to manage overaged coppice stands on slopes is a key question for practitioners: many different strategies have been