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Assessment of soil erosion sensitivity and post-timber-harvesting erosion response in a mountain environment of Central Italy

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ABSTRACT

This study aimed to assess the effects of forest management on the occurrence of accelerated soil erosion by water. The study site is located in a mountainous area of the Italian Central Apennines. Here, forest harvesting is a widespread forestry activity and is mainly performed on the moderate to steep slopes of the highlands. Through modeling operations based on data on soil properties and direct monitoring of changes in the post-forest-harvesting soil surface level at the hillslope scale, we show that the observed site became prone to soil erosion after human intervention. Indeed, the measured mean soil erosion rate of 49 t ha^{-1} yr^{-1} for the harvested watershed is about 21 times higher than the rate measured in its neighboring undisturbed forested watershed (2.3 t ha^{-1} yr^{-1}). The erosive response is greatly aggravated by exposing the just-harvested forest, with very limited herbaceous plant cover, to the aggressive attack of the heaviest annual rainfall without adopting any conservation practices. The erosivity of the storms during the first four months of field measurements was 1571 MJ mm h^{-1} ha^{-1} in total (i.e., from September to December 2008). At the end of the experiment (16 months), 18.8%, 26.1% and 55.1% of the erosion monitoring sites in the harvested watershed recorded variations equal or greater than 0–5, 5–10 and >10 mm, respectively. This study also provides a quantification of Italian forestland surfaces with the same pedo-lithological characteristics exploited for wood supply. Within a period of ten years (2002–2011), about 9891 ha of coppice forest changes were identified and their potential soil erosion rates modeled.

1. Introduction

Climate change, globalization and the growing demand for energy and raw materials are predicted to result in increased demand for forest resources at the European scale (UNECE/FAO et al., 2010). It is estimated that in 2010 about 420 million m^{-3} of roundwood was harvested in the European Union 27 nations to meet the domestic timber demand (EUROSTAT, 2011). According to EUROSTAT (2011), a relatively steady rise was observed in the level of roundwood production in the European Union 27 between 1995 and 2007, both for coniferous (softwood) and non-coniferous (broadleaved or hardwood) species. Studies assume a rising wood demand due to socio-economic expansion during the coming decades in Europe (Parikka, 2004; UNECE/FAO et al., 2007).

In Italy, forestland is the second most common type of land use, covering about 87,592 km^2 or 29% of the land surface, of which 42% is currently managed as coppice forest (INFC, 2007). As a result, a vast area of the country, mostly located in vulnerable mountainous landscapes that are highly sensitive to environmental changes, is subject to anthropogenic disturbance (Gallucci, 2009). The most common and widespread form of forestry is coppice harvesting (Chirici et al., 2011), the only clear-cut system allowed in Italy (Cullotta et al., 2008). Most of the clear-cuts typically range from 1 to 3 ha in size (Chirici et al., 2011; Borrelli, et al., 2013).

As aerial photos of post-harvesting areas show, the described practices of land resource exploitation are carried out without applying appropriate conservation practices within a large part of the Italian forestland. This occurs although several national and international studies (Dissmeyer and Foster, 1984; Edeso et al., 1999; Iovino, 2009) have explicitly called for effective conservation practices to mitigate the post-harvesting impacts on the ecological forest cycles. The neglect of appropriate environment conservation practices may result in irremediable damage, especially in sensitive environments (Scheffer et al., 2001).

Besides the well-known challenges of decreasing forest hydrological functions (Bosch and Hewlett, 1982; Moore and Wondzell, 2005) and biodiversity (Torrasa and Saura, 2008), researchers have also recorded a substantial increase in the geomorphological processes of land degradation such as soil degradation and mass movements (Pennock and Van Kessel, 1997; Imaizumi et al, 2007). The most serious risk, however, results from soil erosion by water, which is one of the most pressing environmental threats worldwide (Reich et al., 2000). The European Mediterranean countries are particularly susceptible to erosion because

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they are subject to prolonged dry periods followed by heavy bursts of intensive and erosive rainfalls falling on steep slopes characterized by fragile soils (Van der Knijff et al., 1999; Grimm et al., 2003).

Logging operations together with wildfires (Rab, 1994; Cerdá and Doerr, 2005; Shakesby, 2011; Smith et al., 2011) are the major factors that can lead to significant changes to erosion rates of forestlands, with an ample window of disturbance (Cerdá and Lasanta, 2005). Both cause soil profile disturbance, exposing the underlying bare mineral soil to the erosive forces of raindrop impact (Dissmeyer and Foster, 1981). The occurrence of high erosion rates in disturbed forests may results in on-site and off-site environmental impacts (Sidle, 1980). On-site impacts include removal of the forest litter layer (Houghton et al., 1983), changes to surface characteristics (Imaizumi and Sidle, 2012), breakdown or alteration of the soil structure (Dyrness and Youngberg, 1957), decline in nutrients and organic matter in the soil (Hornbeck, 1975; Covington, 1981), the alteration of niches for animals (Pimentel and Kounang, 1998) as well as soil compaction (Kozlowski, 1999). Further on-site impacts are the reduction of infiltration and water storage capacities (Iovino et al., 2009), the possible formation of soil surface crusts with consequent compaction of the soil (Smith et al., 2001) and significant run-off increases (Bosch and Hewlett, 1982). By contrast, off-site effects due to increased soil erosion on the hillslopes can result in increased bedload transport (Roberts and Church, 1986) and ecological disturbance in the river network (Marks and Rutt, 1997). Beyond that, sediments transported downstream into the drainage network can cause infilling of artificial lakes and reservoirs (Ciccacci et al., 1983; Romero-Díaz and Martínez-Lloris, 2007). This accumulation of material in reservoirs can reduce drinking water quality (Sopper, 1975) and storage capacity (Bazzoffi et al., 1996), diminish the function of the hydro-electricity dams (Fanelli et al., 2000) and can cause problems of channel instability (Poesen and Hooke, 1997).

Despite widespread forest logging in Italy and the resulting considerable risk of accelerated soil erosion, only very few studies focus on field observations of this phenomenon (e.g., Porto and Walling, 2012). This study aimed to assess the effects of forest management on the occurrence of accelerated soil erosion by water. The study site is located in a mountainous area of the Italian Central Apennines. Here, forest harvesting is a diffuse forestry activity and is mainly performed on the moderate to steep slopes of the highlands. This study assesses soil susceptibility to water erosion with reference to site-specific conditions using the Revised Universal Soil Loss Equation (RUSLE) (Dissmeyer and Foster, 1981; Renard et al., 1997) and models hillslope erosion responses following wood harvesting for not only the study area but also other Italian areas with the pedo-lithological and land use patterns common to the study area.

2. Study area

Two first-order watersheds were selected for direct observations and quantifications of the topsoil morphological evolution under two different forest management approaches. The watersheds (Fig. 1), hereafter referred to as 'harvested EX-01 watershed' and 'undisturbed EX-02 watershed', are located in a remote mountain location inside the Regional Nature Reserve of Monti Cervia and Navegna (Central Italy — 42°12′07.41″N and 13°02′19.54″W; WGS84). The harvested EX-01 watershed stretches from 939 to 1034 m a.s.l. with an area of 1.97 ha. The length of the main stream is 196 m and the mean catchment width is 80 m. The mean stream gradient is 11° and the mean slope gradient is 24°. The undisturbed EX-02 watershed presents similar topographical characteristics within an investigated area of 2.24 ha (Table 1).

Both watersheds were incised into Middle-Miocene flysch rocks with pelitic–arenaceous facies (Carminati et al., 2007). The predominant soil is immature yellow–brown Endoleptic Cambisol (7.5YR3/2–10YR4/4), formed by the alteration of the parent material. The average annual rainfall according to the data from the Collalto Sabino meteorological station (1000 m a.s.l.) for 1921 to 1984 is 1270 mm, and the average annual temperature is 11.3 °C.

The harvested EX-01 watershed belongs to the forested sectors of the Salto watershed where coppicing silviculture is practiced. The coppice trees (mainly *Acerus* sp., *Quercus pubescens*, *Ostya carpinifolia and Quercus* sp.) have grown naturally without any pruning since the last timber harvesting in 1994. Between March 2008 and December 2009, the tree vegetation of the harvested EX-01 watershed was harvested entirely using the shelterwood technique (about 150 trees ha^{-1} standing after clear-cut). The harvesting operations were performed in two steps. The first cut involved the central southern sector, which amounted to 78% of the total watershed surface between May 2008 and June 2008. Then, the remaining 22% of tree vegetation was cleared in November 2009. In contrast, the undisturbed EX-02 watershed has not been involved in timber-harvesting activities even though it borders the harvested EX-01 watershed. The vegetation in the undisturbed EX-02 watershed is a mixed forest of coppice trees similar to those in

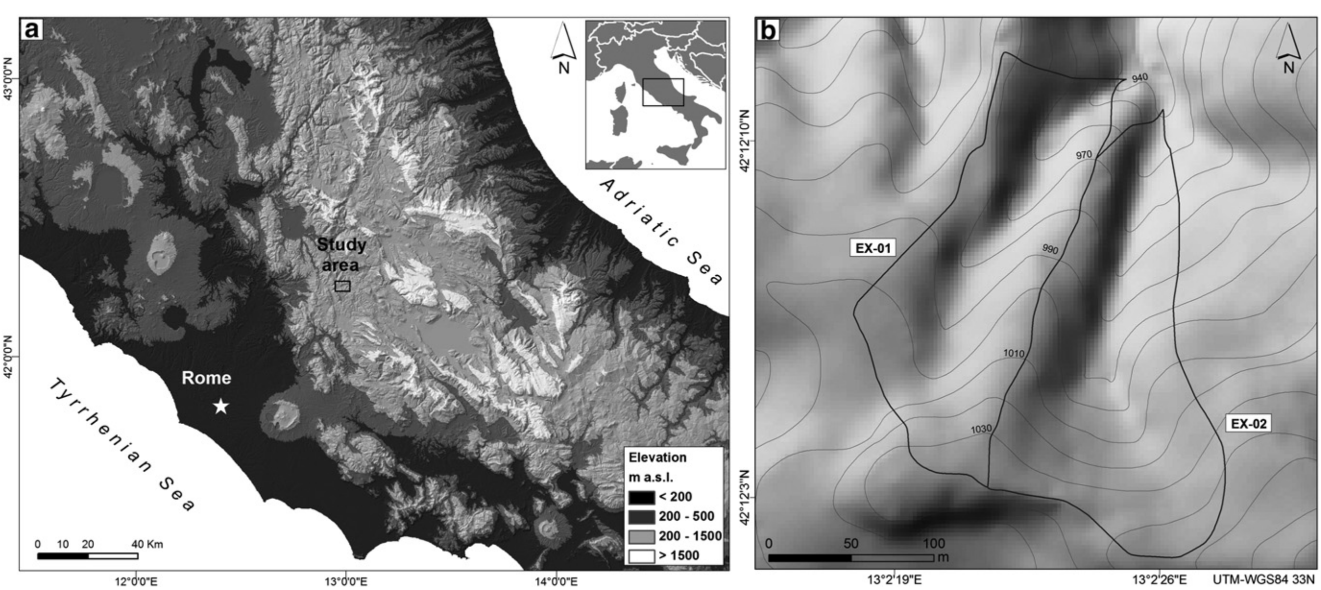

Fig. 1. Study sites. a) Location of study sites in the Central Apennine region, based on the DEM SRTM data V4. b) Detail of the study sites. Background map: hillshade derived from a 2.5 m DEM.
Technical Topographic Map of the Latium Region, scale 1:10,000