SOIL CONSERVATION IN A FORESTED MOUNTAIN CATCHMENT

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Abstract

In 1982–2015, environmental impacts of commercial forestry practices were studied in the Jizerka experimental catchment (the Jizera Mountains, Czech Republic). Skidding the timber by wheelled tractors caused 10.3 km^{-1} of skid trails and the drainage density increased from 1.45 to 7.55 km^{-1}. On the harvested runoff plots, not affected by skid trails, the loss of soil 0.007 - 0.014 mm year^{-1} was comparable with undisturbed forests. But, the eroded soil in skid trails reached 6.17 mm (61.73 m^3 ha^{-1}) by harvesting 23,882 m^3 of timber (i.e. 0.25 m^3 per 1 m^3 of harvested timber). At the catchment outlet, sediment yield reached 25% of the soil eroded. Natural regeneration of erosion rills was supported particularly by the development of herbaceous vegetation. In 2003, twelve years after the logging, only 1.5 km (15 %) of active deeper rills were still identified.

Keywords: *mountain catchment, acid rain, forestry practices, soil erosion, natural recovery.*

Introduction

Topsoil erosion has been supposed as the most ultimately destructive process of soil degradation (Hillel, 2008). It results in the loss of soil productivity and off-site effects by mobilisation of agricultural chemicals and deposition of sediments. In the landscape-scale, Forman (1995) articled the role of forests as benefits on reducing drainage network connectivity, stabilisation of slopes, and protection of soil and water quality. In Europe, approx. 70 percent of forests are controlled by management plans, and 25 percent are registered as forests of non-wood services with priorities in soil and water conservation (FOREST EUROPE, 2015). Effects of commercial forest practices on soil erosion are reported by O'Loughlin and Pearce (1984), Akbarimehr and Naghdi (2012), but, there are still uncertainties in their broader environmental consequences. In the 1980s, in central Europe, the acid rain calamity lead to large-scale forest dieback and extensive timber harvest. The aim of this study is to analyze effects of forest clear cutting on drainage connectivity, soil erosion and sedimentation, and the natural recovery of a small headwater catchment in the Jizera Mts. (Czech Republic), 1982-2015.

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Material and methods

Study area

The study was performed in the upper plain of the Jizera Mts. (Fig. 1): the Jizerka experimental catchment (50°48’21” - 50°48’59”N, 15°19’34” - 15°20’48” E, Elbe river district 1-05-01-004) operating since 1981.

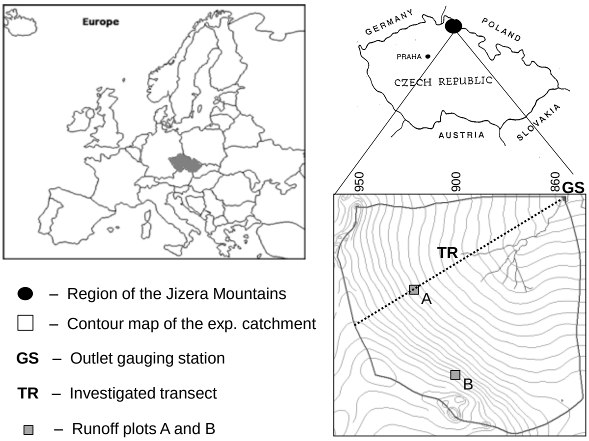

Figure 1
Jizera Mts. Region and the Jizerka experimental catchment.

This area belongs to the North temperate climate zone (Kőppen Dfc - sub-arctic region) with mean annual precipitation 1,400 mm, and mean annual air temperature 4°C (Tolasz, 2007). Low-base-status soils (sandy-loamy Podzols) developed on porphyritic granite achieves the depth from 0.5 to 1.2 m. Native forests include namely Norway spruce (*Picea abies*) and Common beech (*Fagus sylvatica*), but spruce plantations dominate since the second half of the 18th century. In the 1980s, the acid atmospheric deposition, followed by insect epidemics, defoliation and large-scale die-back of spruce plantations leaded to a forest calamity. After the clear-cut (1984–1988), grass communities *Junco effusi-Calamagrostietum villosae* became dominant, and has prolonged the forest regrowth (Křeček et al., 2010).

Catchment monitoring

In 1982, the Jizerka catchment was instrumented by the sharp-crested V-notch weir with the automatic water level recorder at the stream-outlet. The volume of sediment has been estimated annually by changing bathymetry of the sedimentation pond (Fig. 2): the depth was measured manually in one-meter step using rubber boat moving in fixed cross sections. Along the basin transect TR standard meteorological observations were carried out in elevations 875 and 975 m.

Two elementary runoff plots (not affected by skid-trails), 30x30 m area, homogeneous slopes of approx. 10° (Plot A) and 20° (Plot B) were established to collect soil loss by 30 m long trenches covered with geotextile filter fabric (Fig. 1). Within the catchment area, inventory of erosion rills in skid trails was accomplished in summer months of 1983 (before the harvest), 1985, 1990, 1995, 2003 and 2015.

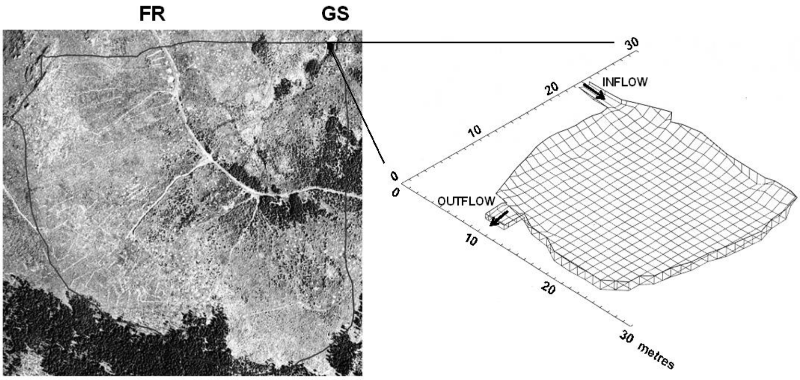

Figure 2 *The Jizerka catchment after the forest harvest (1999).*

FR – Forest timber truck road
GS – Outlet gauging station with sedimentation pond

The volume of erosion rills V (m3) was calculated by the volumetric equation [1]

$$V = \sum 0.5\ (Ai\text{-}1 + Ai)\ D \qquad [1]$$

where: Ai – area of crossection i (m2), Ai-1 – area of crossection i-1 (m2), D – distance between crossections (m).
Renard et al. (1997) proposed the empirical concept of revised universal soil loss equation (RUSLE) to predict the loss of soil by water erosion [2]

$$A = E\ I30\ K\ (L/72.6)m\ (a \sin \Theta + b)\ C\ P \qquad [2]$$

where: A – average annual soil loss (tons acre-1 year-1), E – storm rainfall energy (102 foot-tons acre-1), I30 – maximum rainfall intensity in a 30 minute period within a storm (inch hour-1), K – soil erodibility factor (-), L – slope length (feet), m – slope length exponent, Θ – slope angle (degrees), a, b – coefficients in function making up slope term – values depend on slope (-), C – cropping management factor (-), P – conservation practice factor (-).

The size of eroded soil in the skidding lines was compared with the extent of harvested areas and volumes of harvested timber. On the whole, 156 phytosociological relevès (squares of 4 x 4metres) were investigated to analyse the herb layer development: this monitoring included 53 deep, 33 medium and 38 shallow rills, 15 plots with dead spruce stands, and 17 clear-cut spots. In the implemented phytosociological relevès, all species abundance was estimated, and the data transformed from Braun-Blanquet scale to 9-point scale of Van der Maarel (1979). Using the information on higher plants only, following characteristics were evaluated: percentage cover of herb layer; species richness (total species number

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per relevè); life form categories of Raunkiaer (1934) according to Ellenberg et al. (1992). ANOVA statistics was used to test differences in the vegetation features among particular stands and age groups. The archive of LANDSAT imagery (NASA, 2014) was used to identify changes in the vegetative cover in the studied catchments (resolution of 30 m) in 1983–2016. Only clear-sky images collected in the high summer (June-August) were taken into account. From the multi-band raster images, five canopy classes were identified in the consecutive years 1983 – 2015 (Křeček and Krčmář, 2015). These classes (mature spruce forests, stands of the crown closure above 0.3, reforested plots with the crown closure below 0.3, areas covered only by grass communities, and clear-cut) correspond with the definition of "forest" used by the *United Nations Framework Convention on Climate Change*: crown closure > 0.3, and height >2–5 m at maturity), Sasaki and Putz (2009).

Results

Canopy changes

Initially, the Jizerka catchment was covered by mature spruce stands. In 1984, 62 % of the catchment area was harvested by clear-cutting, and about 88 % was harvested at the end of the 1980s. Canopy changes in 1982-2015 were reconstructed from the multi-band imagery (Fig. 3).

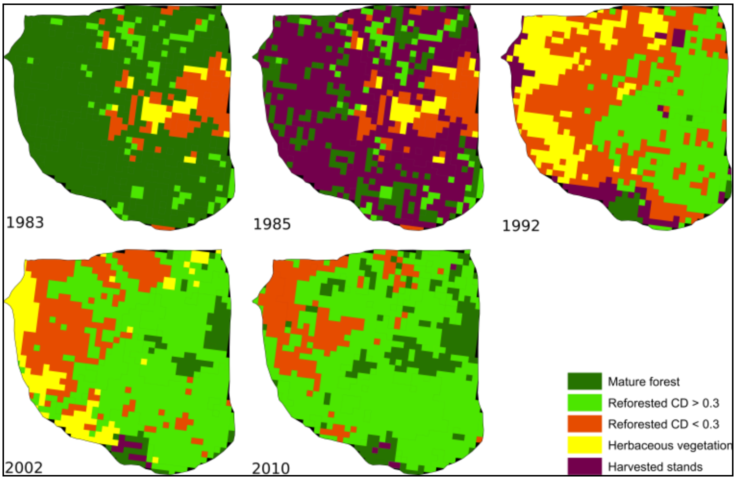

Figure 3
Canopy in the Jizerka catchment, 1983-2010 (CD – crown closure of trees).

Drainage network development

In the Jizerka catchment, before the forest harvest (Fig. 4), the drainage network was formed by 1,490 m of stream channels, the drainage density was 1.45 km^{-1} exceeding five times the value of 0.26 km^{-1} considered by Pallard et al. (2009) as critical for the risk of flooding. In 1984-1990, 10.3 km of skidding trails originated with the timber harvest; 6.1 km of rills deeper than 25 cm were directly connected with the existing drainage system. Thus, the drainage density increased from 1.45

to 7.55 km^{-1}. With the natural regeneration, in 2003, only 1.5 km of active deeper rills (connected with the drainage network) and 1 km of shallow rills were identified (Fig. 4), and this situation did not change in 2015.

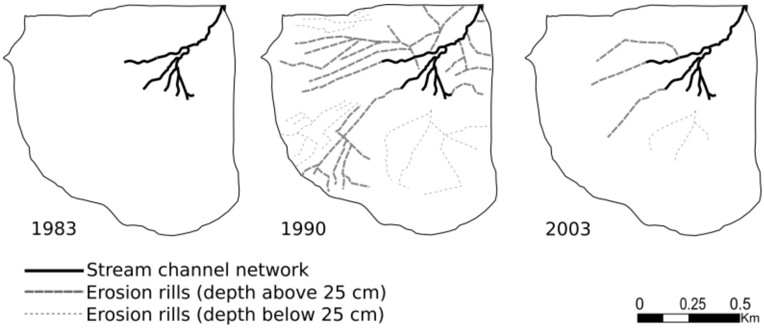

Figure 4
Drainage network and erosion rills in the Jizerka catchment before (1983) and after the forest harvest (1990, 2003).

Soil erosion loss and sedimentation

Considering RUSLE parameters in the Jizerka catchment (Fig. 1), the maximum 30 minute rainstorm intensity I_{30} = 39 mm, soil erodibility factor K = 0.26, and alternative values of the cropping management factor C (0.002 – coniferous forests, 0.09 – grassland, and, 0.325 - disturbed forest land, according to Panagos et al., 2015). The predicted loss of soil achieves maximum values 0.0239 t ha^{-1} $year^{-1}$ (spruce stands), 1.38 t ha^{-1} $year^{-1}$ (grassland) and 5.01 t ha^{-1} $year^{-1}$ (disturbed forest). Thus, for the scenario of clear-cut disturbances at Jizerka, predicted loss of soil might reach maximum 30 mm per year in extreme hill sites. Annual values of the soil loss observed in harvested runoff plots A and B are relatively small at both slopes (10^o and 20^o): 0.007 and 0.014 mm $year^{-1}$ corresponding with those of undisturbed forests (Elliot et al., 1996). These plots were not damaged by skid trails, thus, the litter cover and herbaceous understory protected well the soil surface.

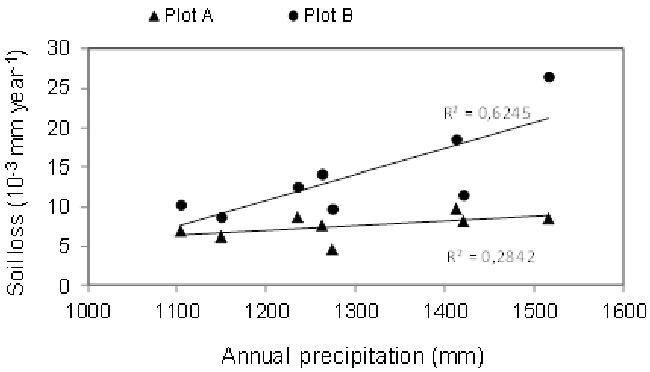

Figure 5
Soil loss and annual precipitation in the runoff plots A and B.

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The washed soil included particles of raw humus (65%) and fine sand (35%). In the higher slope (plot B), there is a significant correlation of the annual loss of soil with annual precipitation ($R = 0.79$, $R_{crit} = 0.71$, $p = 0.05$, $n = 8$), contrary to the lower slope (plot A), Fig. 5.

The development of erosion rills and volume of eroded soil with the harvest of timber (and reduce in the area of mature stands) is given in Fig. 6. After the timber harvest, in 1990, the total length of 10.3 km significant skid trails represented volume of 8,122 m^3 erosion rills. From ten detailed skid trail profiles on slopes 5 – 15^o, there was found in average 24% of that volume lost by crushing out and soil compaction.

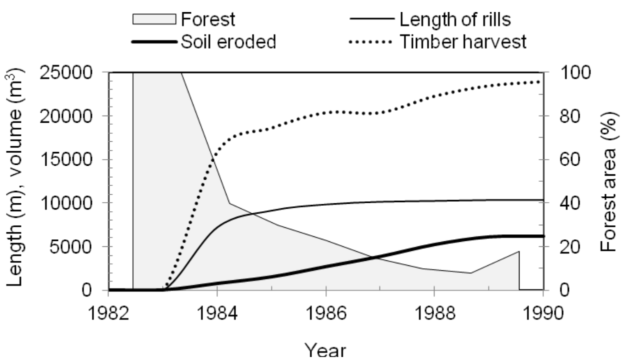

Figure 6
Cumulative growth of rills and eroded volume of soil with forest harvest: the Jizerka catchment (1982-1990).

Therefore, in 1984 – 1990, the total transport of soil from the network of erosion rills was approx. 6,173 m^3 (i.e. 61.73 m^3 ha^{-1}, or 6.17 mm). By the harvest of 23,882 m^3 of timber (i.e. 238.82 m^3 ha^{-1}), the loss of soil was 0.25 m^3 per each 1 m^3 of harvested timber. Annual values of sediment yield observed at the catchment outlet are in Fig. 7.

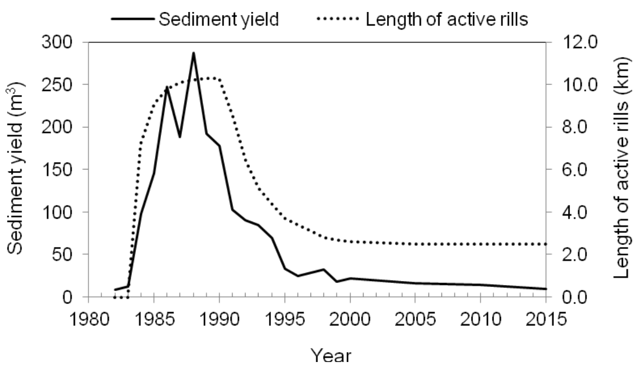

Figure 7
Annual sediment yield and length of active erosion rills: the Jizerka catchment (1980-2015).

Before the harvest (1982-1983), the annual sediment yield was 0.01 mm $year^{-1}$; while in the harvest period (1984-1990), the total yield of sediment was 1.34 mm (i.e. 0.19 mm year^{-1}). Thus, in the harvest period, sediment yield increased 19 times, and accomplished 22% of the volume of soil (6.17 mm) transported from the network of erosion rills (skid trails). In 1991-2015, the length of active erosion rills has decreased from 10.3 to 2.5 km by natural regeneration (Fig. 7); the total volume of sediment yield 1,525 m^3 represents 25% of the eroded soil in the skid trails (6,156 m^3).

Natural recovery of skid-trails

In the Jizerka catchment, a long-term defoliation of spruce stands and the extended clear-cut led to relatively low species richness in herb layers with dominating *Calamagrostis villosa*. In all investigated relevès, only 48 plant species were identified; the stand characterization included: dead forests with the herb layer covering 100% of the area and low number of species (maximum 6 per relevè), forest clearings with the herb cover 95-100% and number of species 5-10, middle erosion rills (between 25 and 50 cm) with plant cover 20-75%, and species richness 4-9, and deep erosion rills (depth above 50 cm) with plant cover only 1-30% and variable species richness (1-9). The species composition in forest clearings is associated with the harvested forest type and former composition of the herb layer (Nováková and Křeček, 2006). Plant cover was affected particularly by the depth of erosion rills (R^2 = 0.42), few species were present noticeably rarely in the middle and deep rills in comparison with the other stands (e.g. *Calamagrostis villosa*, *Galium harcynicum, Vaccinium myrtillus*). Considering growth forms, the percentage of plants forming tillers decline gradually from clearings and dead forests (almost 40%) to shallow (33%) and deep rills (29%), in the same direction, the proportion of plants forming clusters increased from 60 to 71%. Within the life forms, hemicryptophytes dominate, they form 70-80% of species present in rills and dead forest stands against only 60% present in clear-cut areas. Only a weak positive correlation (R = 0.21, p = 0.091) was found between the species richness and slope. After the forest harvest, a relatively fast natural rehabilitation of shallow rills (depth below 25 cm) was observed: about 15% of their surface has been covered by grass (mainly hemicryptophytes) in 3 years, and 80% in 10 years after timber skidding. In deep rills, there is slightly higher proportion of stress-tolerant plants (45%) in comparison with shallow rills.

Discussion and conclusions

Before the timber harvest, in the Jizerka catchment, the annual sediment yield (0.01 mm year^{-1}) is below the approximate annual soil genesis (0.036 mm year^{-1}, given for a mountain environment in the humid temperate climate by Vladychenskiy, 2009); but, the clear-cut (1984-1990) led to exceeding the rate of soil genesis by four times in 12 consecutive years of 1984-1995. In 1996-2015, the sediment yield (0.021 mm year^{-1}) is back below the rate of soil formation. However, still in 1996-2015, the mean annual sediment yield (0.021 mm year^{-1}) is higher in comparison

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with values (0.01 mm year^{-1}) before the harvest (1982-1984). After the forest harvest, a relatively fast natural rehabilitation of shallow rills (depth below 25 cm) was observed: about 15 % of their surface has been covered by grass (mainly hemicryptophytes) in 3 years, and 80 % in 10 years after timber skidding. The rate of erosion in skid trails is driven particularly by their depth and slope (Elliot et al., 1996); but, the depth of rills depends also on the frequency of timber skidding and hydrological conditions (Nearing et al., 1997). In deep rills at Jizerka was found a higher proportion of stress-tolerant plants (45%) in comparison with shallow rills; it confirms the low nutrient availability at the places where the top soil horizon was removed (Urbanska and Fattorini, 2000). In Central Europe, 250 years tradition of sustainable forest management has respected the ecosystem approach on multiple functions as well as conservation of soil and water (Spathelf, 2010). However, exogenic calamities (like the large scale acid rain impact) could affect this approach for a relatively longer period. In the Jizerka catchment, the signs of higher sediment runoff are remarkable from 1984 to 2015. There are several management practices used in forestry operations to mitigate the impact of logging, forest road and skid trail construction on stream water quality (Wallbrink and Croke, 2002, Spathelf, 2010): these practices are designed to control erosion and to minimize the delivery of sediments to drainage lines. Theoretically, with respect of those regulations in the forest clear-cut at Jizerka, it was possible to avoid the significant loss of soil by keeping the benefit of reducing the acid atmospheric load (Křeček et al., 2017).

Aknowledgements

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CONSERVATION DES SOLS EN BASIN DE MONTAGNE FORESTIER

Résumé

De 1982 à 2015, les impacts environnementaux des pratiques forestières commerciales ont été analysées dans le basssin experimental Jiserka situé dans les montagnes Jizera en République tchèque. Le débusquage d'arbres par les tracteurs à roues ont causé l'envasement des sentiers sur 10.3 km^{-1} et l'augmentation de la densité de drainage passant de 1.45 to 7.55 km^{-1}. Sur les parcelles de ruissellements récoltées non affecté par l'envasement des sentiers, la perte annuelle des sols de 0.007 à 0.014 mm 0.007 - 0.014 mm^{-1} était comparable avec les forêts où il n'y a pas de pratiques forestières commerciales. Mais le sol érodé dans les sentiers envasés a atteint 6.17 mm (61.73 m^3 ha^{-1}) par la récolte de 23,882 m^3 de bois (c-à-d. 0.25 m^3 par 1 m^3 de bois récolté). À la sortie de captage, le rendement sédimentaire du sol érodé a atteint 25%. La regénération naturelle de l'érosion des ruissellements était compensée par la végétation herbacée. In 2003, douze années plus tard, seulement 1.5 km (15 %) des zones de ruissellements actifs étaient toujours repertoriées.

Mots-clés: *bassin de montagne; pluie acide; pratiques forestières; érosion du sol; récupération naturelle.*

CONSERVAZIONE DEL SUOLO IN UN BACINO MONTANO BOSCATO

Riassunto

Gli impatti ambientali delle utilizzazioni forestali sono stati studiati fra il 1982 ed il 2015 nel bacino sperimentale di Jizerka (Jizera Mountains, Repubblica Ceca). Il trascinamento dei tronchi per mezzo di trattori forestali ha causato la formazione di 10.3 km^{-1} di piste di esbosco ed un aumento della densità di drenaggio da 1.45 to 7.55 km^{-1}. In partelle sperimentali sottoposte a taglio ma non interessate da piste di esbosco la perdita di suolo variava fra 0.007 - 0.014 mm $year^{-1}$, risultando confrontabile con quella della foresta indisturbata. L'erosione del suolo lungo le piste di esbosco, al contrario, raggiungeva 6.17 mm (61.73 m^3 ha^{-1}) rispetto all'asportazione di 23,882 m^3 di legname (0.25 m^3 per 1 m^3 of legname). Alla sezione di chiusura del bacino la produzione di sedimento risultava pari al 25% del suolo eroso. La rigenerazione naturale dei solchi di erosione è stata determinata principalmente dallo sviluppo di vegetazione erbacea. In 2003, dodici anni più tardi, solo 1.5 km (15 %) dei solchi di erosione attivi più profondi potevano ancora essere identificati.

Parole chiave: *bacino montano; piogge acide, pratiche forestali; erosione del suolo; ripristino naturale*