Surface erosion in cleared and uncleared mountain windthrow sites

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Abstract
This study focused on the erosion processes in scars inflicted by storm Vivian. The windthrow study sites of Pfäfers, Schwanden and Disentis were investigated in relation to the soil characteristics and the plot treatments “uncleared”, “cleared”, “planted” (SCHÖNENBERGER this issue). Thirty-five erosion scars (ES) were selected in 1992, and erosion activity was assessed by measuring the changes in their surface areas between 1992 and 2000. Furthermore, soil samples were taken to establish the grain size distribution. From a geotechnical point of view, the erodibility of the soil material increases between that in Disentis and Schwanden and that in Pfäfers. Nevertheless, on the “cleared” as well as the “planted” treatments at Pfäfers, the soil material proved better for vegetation re-establishment than on the same treatments in Schwanden and Disentis. During the investigation period (1992–2000) eight new ES developed, indicating that the soil stability of the study sites had entered the delicate phase when the contribution of the rotting roots of the old stand to soil stability has fallen below a critical point and the new vegetation has not yet developed enough to compensate for this loss of stability. A slight tendency towards a positive correlation between erodibility and inclination was found. The key factors controlling the re-establishment of vegetation cover on ES were deduced to be the soil material, followed by the inclination and the different treatments. In addition, it can be concluded that careful selection of the wood harvesting method and its appropriate application will help prevent the development of erosion scars.

Keywords: windthrow, erosion, grain size distribution, vegetation re-establishment, slope inclination, Switzerland

1 Introduction

The storm Vivian caused widespread windthrow and uprooting, leading to countless erosion scars (ES). These scars, denuded of the protecting vegetation, immediately became directly exposed to the weather. This raises the questions of 1) whether ES in windthrown stands will lead to significant erosion problems, and 2) what factors influence the re-vegetation of the ES; e.g. does clearing increase increase erosion processes?

Within the scope of the present study the development of ES was investigated at three different study sites. The focus was on the analysis of possible correlations between the ES and the erosion processes. Particular attention was paid to the influence of the soil characteristics and the different treatments of the windthrown stands on the erosion risk after Vivian. Furthermore, the findings of this study are discussed in view of soil development, in particular the formation of soil aggregates composed of fine fractions, and compared with the results of a recent investigation about the effects of forest condition on landslide activity.
2 Material and methods

For the analysis of erosion processes, 35 original erosion scars (ES; subsequently called “original ES”) with a minimal area >16 m² were assessed in 1992 at the three Vivian windthrow study sites Pfäfers, Schwanden, and Disentis. For each of these original ES, the size and shape of the surface as well as the inclination were recorded. Furthermore, their vegetation cover was estimated. Eight years later, in 2000, the parameters were recorded again. In addition, ES that developed after 1992 (subsequently called “new ES”) were registered. New ES were not included in the evaluation of the vegetation re-establishment on the original ES.

For geotechnical investigations three soil samples of 20 kg to 25 kg were taken from each of the study sites. In the laboratory, the grain size distribution of each sample was established by sieve analysis following the protocol of VSS (1997). Taking the grain size distribution as a basis, the angle of shearing resistance $\Phi$ was estimated after LANG et al. (1996) and, in addition, the erodibility was assessed using COPPIN and RICHARDS’ (1990) method.

3 Results

3.1 Development of the total area of erosion scars

When the first data were acquired in 1992, the total surface area of the 35 original ES was 2690 m². Their average surface was 77 m², ranging from 17 m² to 434 m² with a standard deviation of 83 m². In 2000, 19 of the 35 original ES were still active (Table 1). Consequently, the portion of eroded area was cut in half from 1.6% in 1992 to 0.8% in 2000 (Fig. 1a). However, between 1992 and 2000, shallow landslides had produced eight new ES, with a mean surface area of 120 m², ranging from 12 m² to 351 m², with a standard deviation of 111 m². Seven of them (the result of heavy rainfall in August 2000) are in Pfäfers and one in Schwanden. In 2000 the total area of all ES, i.e. the remaining 19 of the original 35 and the eight new ones, was 2380 m². This is only 310 m² less than the area of the original ES registered in 1992. Therefore, the total portion of eroded area of all study sites decreased only marginally from 1.6% in 1992 to 1.4% in 2000.

3.2 Vegetation re-establishment at the different study sites and treatment

Figure 1a shows that the proportion of eroded area in 1992 in Pfäfers was three times greater than in Disentis and Schwanden. At Pfäfers the progress of vegetation re-establishment was slower than at the other study sites, because of the substantial proliferation of one single original ES within the “uncleared” treatment.

In 1992 only five of the 35 original ES were situated within the “uncleared” treatments of the three study sites. Seventeen original ES were located within the “cleared” treatments and 13 within the “planted” treatments (Table 1). The proportion of eroded area varied between 0.9% in the “uncleared” treatments, 1.5% in the “planted”, and 2.3% in the “cleared” treatments (Fig. 1b).
Table 1. Study sites and treatments: mean slope inclination and size of the treatments, number of original erosion scars (ES) in 1992, number of recovered original ES in 2000, number of new ES between 1992 and 2000.

<table>
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<tr>
<th></th>
<th>uncleared</th>
<th>cleared</th>
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<th>all treatments</th>
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<td>85</td>
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<td>35</td>
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<td>19</td>
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<tr>
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Fig. 1. The proportion of eroded area (1992, original ES in 2000, new ES 1992–2000) at the different study sites (Fig. 1a) and within the different treatments (Fig. 1b).
By 2000, the proportion of eroded area within the “uncleared” treatments had increased by 40% due to the substantial enlargement of one single original ES in Pfäfers. Furthermore, three new ES developed in the “uncleared” treatment in Pfäfers. In Schwanden as well as Disentis, neither original nor new ES were registered in the “uncleared” treatment.

The surface of the original ES of the “cleared” treatment decreased by 56% from 1992 to 2000. Vegetation re-establishment was best in Pfäfers, i.e. 1.5-times better than in Disentis and 2-times better than in Schwanden. Four new ES were registered in the “cleared” treatment, all of them in Pfäfers.

In the “planted” treatment 98% of the surface area of the original ES had been recovered by vegetation by 2000. In Schwanden one new ES was recorded in the “planted” treatment.

3.3 Slope inclination and vegetation re-establishment

Figure 2 shows the correlation between the inclination and the vegetation re-establishment between 1992 and 2000 of the original ES. Despite the pronounced scatter there is a tendency for the re-establishment of vegetation cover to decrease with increasing steepness of the original ES. The average inclination of the study site in Schwanden is 68%, which is clearly less steep than in Pfäfers and Disentis both with 94% inclination. With reference to treatments, the “cleared” and the “uncleared” research plots, with average slope inclinations of 85% and 87%, respectively, are steeper than the “planted” ones with 73% inclination (Table 1).
3.4 Geotechnical analyses

The results of the sieve analyses are illustrated as summation curves in Figure 3. Each study site is represented by a mean curve of the three corresponding analyses. The soil samples taken from Schwanden and Disentis show a close affinity in their grain size distribution, characterised by a comparatively small clay and silt fraction. The soil material collected at Pfäfers is characterised by its substantial portion of small grain sizes. The angle of shearing resistance $\Phi'$ derived from the grain size distribution varies between $35^\circ$ and $37^\circ$ for Schwanden and between $37^\circ$ and $39^\circ$ for Disentis. The angle of shearing resistance for Pfäfers lies between $25^\circ$ and $33^\circ$ and, consequently, the soil stability there is considerably less.

In addition, an assessment of erodibility according to COPPIN and RICHARDS (1990) indicates that the soil in Pfäfers is distinctly more susceptible to erosion than that in Schwanden or Disentis (Fig. 4).

Fig. 3. Summation curves of the grain size distribution at the three study sites Pfäfers, Schwanden and Disentis. Each curve represents the average of three corresponding sieve analyses.

Fig. 4. Soil susceptibility to erosion (after COPPIN and RICHARDS 1990) of the three study sites Pfäfers, Schwanden and Disentis. A: least susceptible, B: moderately susceptible, C: very susceptible, U: most susceptible.
4 Discussion

The original ES within the “uncleared” treatment of the three study sites made up only a small proportion of the erosion surface. Therefore, it is assumed that a considerable part was not directly due to windthrow and uprooting, but rather to clearing and construction work carried out after the storm. For example, logging by cable crane with logs not transported completely suspended but by dragging caused several of the erosion scars. Applying suitable wood harvesting methods more carefully should contribute to reducing erosion problems.

In August 2000 a heavy rainfall triggered seven shallow landslides at Pfäfers. Recent investigations of the relationship between vegetation and shallow landslides show that areas affected by windthrow or bark beetles are highly susceptible to erosion and landslides (RICKLI 2001). O’LOUGHLIN et al. (1982) found that clear cutting, which in this connection may be compared to damaged stands, greatly increased the risk of landslides. The main problem with regard to the soil stability function is probably the transition period between the old stand, damaged, e.g. by windthrow, and the newly developing vegetation. There is a delicate phase when the contribution of the old stand to soil stability falls below a critical point due to advanced root decay and the developing vegetation is not yet ready to compensate for this loss (ZIEMER 1981). Extreme stress, e.g. heavy rainfall, during this period may lead to landslides and erosion. Ten years after the storm Vivian, it seems very probable that this lag phase was at least partly responsible for the development of new ES at the study site in Pfäfers. However, other parameters should not be neglected, e.g. inclination, topography and, particularly, the soil characteristics.

From a geotechnical point of view, the fact that the proportion of fine fractions (<2 mm) in the soil in Pfäfers is up to twice as high as in Schwanden and Disentis partly explains its lower stability. At this study site the high proportions of the clay and silt fractions are mostly responsible for the low angle of shearing resistance $\Phi'$ (LANG et al. 1996) as well as for the high erodibility of the soil material (COPPIN and RICHARDS 1990). This unfavourable situation mainly explains the landslides triggered by the heavy rainfall in August 2000. Basically, a high proportion of fine soil fractions is not necessarily disadvantageous. GRAF and GERBER (1997) showed that on graded ski slopes in the alpine zone high silt and fine sand fractions may positively influence the re-colonisation and growth of plants. In their study, the vegetation on the sites with nominally the most erodable soil was better developed and more abundant than elsewhere. The fine soil fractions are the basic particles for the production of soil aggregates (LYNCH and BRAGG 1985). These are mainly formed and stabilised by micro-organisms and plant roots, as long as re-colonisation starts in good time and is sufficiently extensive (TISDALL et al. 1997). The nutrients within the aggregates are protected from leaching and so contribute to the fertility of the soil. Furthermore, they constitute the matrix of the pore structure and, therefore, enhance water retention capacity (CHENU 1993; PUGET et al. 1999). Both aspects are important requirements for plant growth and establishment. The comparison of all plots with the treatments “cleared” and “planted” supports this theory. In Pfäfers the vegetation re-establishment was 1.5- and 2-times better than in Disentis and Schwanden, respectively, notwithstanding the relatively high inclinations.

The better performance of vegetation re-establishment on the “planted” plots compared to the “cleared” (and naturally re-colonised) ones requires further investigation. The results of the present study do not enable definite conclusions about the effects of either the inclination or the treatments.
5 Conclusions

- Numerous erosion scars (ES) were generated by the clearing up operations and the construction of forest roads and maintenance paths after Vivian.
- A careful selection of wood harvesting methods and their appropriate application considerably decreases the development of erosion zones; e.g. logs should not been dragged but transported fully suspended when using cable cranes.
- In connection with the construction of forest roads and maintenance paths, special attention should be given to the channelling of rain water.
- The better performance of vegetation re-establishment on the “planted” plots compared to the ”cleared” ones cannot be explained on the basis of the present study.
- Inclination and, particularly, soil characteristics are key factors that affect both the vegetation re-establishment in erosion areas and shallow landslides and subsequent erosion.
- The re-establishment of vegetation in erosion zones is negatively correlated with the slope inclination of the area.
- Soil material with a high proportion of fine soil fractions (<2 mm) is highly susceptible to landslides.
- There is an increased erosion risk in fine soil material (<2 mm) with a silt fraction higher than 60%.
- Although a high proportion of fine soil fractions (<2 mm) increases susceptibility to landsliding and erosion from a geotechnical point of view, it can prove advantageous for plant growth and establishment and, therefore, may increase soil stability during vegetation recovery.
- Appropriate silvicultural measures to increase the stability of the forest after windthrow may help to reduce the activity of shallow landslides.

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6 References


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