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Destructive and constructive effects of mudflows – primary succession and success of pasture regeneration in the nature park Sölktäler (Styria, Austria)

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Abstract

In July 2010, several catastrophic mudflows devastated the mountain pastures in the nature park Sölktäler (Styria, Austria). From a nature conservation point of view, mudflows are natural processes that create pioneer habitats. Therefore restoration measures should be avoided in protected areas. On the other hand, mudflows are natural disasters that lead to the devastation of agricultural land. From an agricultural point of view, rapid re-vegetation measures are necessary. As such, there are conflicting interests concerning re-establishment of vegetation in protected areas. Our study was aimed at assessing the initial vegetation development on sown and on untouched (= not sown) erosional and depositional sites both from a nature conservation and an agricultural perspective. For this investigation 59 permanent plots on untouched and 52 permanent plots on sown sites were established in 2011 and 2012. Results show that the natural regeneration of vegetation on humus-free sites is a slow and long-term process due to the extreme abiotic conditions of the site. In an early stage of primary succession the vegetation is, with a few exceptions, characterized by a low vascular plant species richness. Re-vegetation measures using commercial seed mixtures accelerate grassland re-establishment, leading to a species-poor plant community which is dominated by a few sown grass species and legumes. The effects of different restoration measures (liming, application of straw or farmyard manure) on vegetation are discussed in this article.

Keywords

Mountain pastures, pioneer habitats, plant species richness, re-vegetation measures, seed mixture

Mountain pasture heavily affected by the mudflow with massive layers of deposited timber (S. Winter)

Introduction

Mudflows are a common natural phenomenon in mountainous regions world-wide. They are induced by heavy rainstorms or continual rainfall. Mudflows are easily triggered on steep slopes if the soils are water-saturated. Climate change may lead to more frequent heavy rainfall events (Berg et al. 2013). Thus, in mountainous regions the risk of mudflows might increase.

From a nature conservation point of view, mudflows are natural geomorphic processes which create pioneer habitats. Mudflows modify existing landforms through the formation of erosional and depositional zones and thus they increase habitat diversity. Hence in protected areas mudflows should be regarded as a natural process and, therefore, restoration measures should be avoided. On the other hand, mudflows are natural disasters that cause heavy damage to buildings and infrastructure and devastate agricultural land. From an agricultural point of view, re-vegetation measures on heavily disturbed sites are necessary. Thus in protected areas there are conflicting interests concerning re-establishment of vegetation following mudslides.

Today, natural initial ecosystem development can rarely be observed in Central Europe (SCHAAF et al. 2011). Therefore from a scientific point of view mudflows present a great opportunity to study ecosystem development and primary succession from the initial stage.

In July 2010, due to heavy rainfall (120 mm in 3 hours) several catastrophic mudflows led to the devastation of mountain pastures in the nature park Sölktäler. Large areas (220 hectares) of grasslands were covered with mudflow deposits in the valley Schwarzenseetal. Fortunately, the disastrous mudflows did not result in any injuries, but produced substantial damage to roads and bridges. Immediately after this natural disaster 150 hectares of mountain pasture with no or sparse vegetation cover was re-vegetated since pasture was needed for livestock. In order to minimize costs a commercial seed mixture was used. The seed mixture (HR 260) contained the following 11 species: *Trifolium repens, T. hybridum, Lotus corniculatus, Poa pratensis, Festuca rubra, F. pratensis, Phleum pratense, Dactylis glomerata, Lolium perenne, Agrostis capillaris* and *Cynosurus cristatus* (for details see www.hesa.co.at). In addition lime, straw or farmyard manure was applied on some sown areas. The remaining areas of destroyed grasslands, especially areas next to the stream (Schwarzenbach) and on very steep slopes were left to natural succession. Despite of re-vegetation measures, the forage yield of mountain pastures is much lower than before the natural disaster two years ago. So far, the number of livestock has had to be reduced by 40 %.

The aims of our study were:

- documentation, analysis and evaluation of the initial vegetation development on sown and on untouched erosional and depositional zones,
- assessment of the nature conservation and agricultural value of different re-vegetation measures and
- analysis of the potential of plant species to invade the neighboring sown sites from undisturbed sites.

Study Area

The study area is situated in the nature park Sölktäler and in the Natura 2000 Special Area of Conservation "Niedere Tauern" in the northwestern part of the federal state Styria, Austria (47° N, 13° E). The valley where several mudflows occurred, is roughly north to south oriented. The highest mountain peaks extend up to 2,500 m. The entire park area was glaciated during the Pleistocene, resulting in U-shaped valleys with steep slopes. This topographic condition provides optimum terrain for the development and occurrence of mudflows. The bedrock in the study area consists of different types of gneiss (FLÜGEL & NEUBAUER 1984). Glacial and alluvial sediments are prevalent on the valley floor. The climate can be classified as sub-oceanic: the mean annual precipitation exceeds 1,100 mm and the mean annual air temperature is approximately 5.8°C, varying from -2.6 °C in January to 14.6 °C in July. The growing season is relatively short due to the long snow cover, lasting 106 days a year on average. Thunderstorms mainly occur from May to September, also representing the period with peak precipitation (ZAMG 2002). In the study area, the most widespread soil types on freely drained sites are carbonate-free, acid, nutrient-poor Leptosols (Rankers) and Cambisols with a loamy sand texture. The grassland is primarily utilized as pasture during the summer season. The pastures which were devastated by mudflows, are grazed by cattle. The few meadows on the valley floor are cut once a year and are occasionally fertilized with farmyard manure. The pastures are mainly covered with a *Homogyno alpinae-Nardetum* community (*Nardo-Agrostion tenuis* alliance) and the meadows with a *Festuca rubra-Agrostis capillaris* community (*Polygono-Trisetion* alliance). *Picea abies-Abies alba* communities represent the potential natural vegetation in the montane belt. The riparian forest vegetation on the valley floor belongs to the *Alnus incana* community.

Methods

We established 59 permanent plots on untouched sites in 2011 and 2012 and 52 permanent plots on freshly sown sites in 2012. All plots were located in the montane belt (1,000 to 1,300 m a. s. l.). Slope angle varied from 0° on the valley floor to more than 30° on slopes mainly exposed to west or east. All permanent plots on freshly sown sites had the same plot size of 16 m^2 and were largely homogenous concerning topography and debris accumulation. The size of the permanent plots on untouched sites varied from 16 to 36 m^2 due to the different size of the newly established sand or gravel banks. Each plot was permanently marked with large metal nails or hard-rubber pegs (depending on the substrate) that were inserted at two opposite corners of the plots. In addition, we recorded the geographical position in the center of each permanent plot with a GPS device and made photo documentation. In 2011 and 2012, vegetation surveys were carried out at each plot using the methods of BRAUN-BLANQUET (1932) with a modified scale. Furthermore, total vegetation cover, bryophyte cover, cover of species groups (grasses, herbs, legumes), cover of straw layer and type of substrate were recorded. The nomenclature of vascular plant species follows that of FISCHER et al. (2008).

Results and Discussion

Mudflows create new, more or less humus- and vegetation-free surfaces through removal of the humus-rich topsoil. In the study area, mudflow deposits are a mixture of unconsolidated siliceous debris of different grain size. The fine earth fraction is very low at most sites. Both the erosional and depositional areas created by mudflows are characterized by a very low availability of plant nutrients in the almost humus-free substrate, resulting in extreme abiotic site conditions.

The freshly sown and untouched sites differed considerably with regards to total vegetation cover, plant species composition and physiognomy. In the second year following re-vegetation measures, the range of total vegetation cover was between 5 and 90 % (mean: 49 %), mainly depending on the substrate type. On areas with a particularly high content of coarse fragments, re-vegetation measures were less successful than on areas with a higher content of fine-textured substrate. The mean coverage of grasses, herbs and legumes was 56 %, 1 % and 43 %, respectively. Bryophyte cover averaged 4 % (minimum: 1 %, maximum: 20 %). The average number of vascular plant species within a plot size of 16 m^2 was 22 (minimum: 11, maximum: 43).

The vegetation was frequently dominated by *Festuca rubra*, *Agrostis capillaris* and/or *Trifolium repens*. Either *F. rubra* or *A. capillaris* were the dominant grass species. Both species are typical of moderately nutrient-poor soils. *F. rubra* has a wide ecological amplitude and is therefore a successful colonizer in many different habitat types. *Trifolium hybridum*, *Lotus corniculatus*, *Festuca pratensis*, *Phleum pratense*, *Dactylis glomerata*, *Lolium perenne* and *Cynosurus cristatus* were also abundant. All these established species were present in the commercial seed mixture. Among the sown species, only *Poa pratensis* did not establish very successfully so far. The absence of *P. pratensis* on many sown plots can be explained mainly by the slow germination rate of its seeds.

On many sown areas, the cover of nitrogen-fixing legumes was exceptionally high. *T. repens* was often the dominant legume. T. *hybridum* and *L. corniculatus* also reached a relatively high cover. *T. repens* is characteristic of intensively used grasslands, whereas *L. corniculatus* is a typical species of extensively used grasslands, indicating base-rich, nutrient-poor soils. *T. hybridum* naturally occurs in wet meadows. Obviously, the lack of humus causes a nitrogen deficiency in the mudflow deposits, which in turn limits the growth of some grass species, particularly *L. perenne* and tall grasses such as *D. glomerata*, *F. pratensis* and *P. pratense* did not grow vigorously. Since legumes are almost independent of the nitrogen supply from the substrate (LLOYD & PIGOTT 1967), they achieved high cover on many sown areas, gradually increasing the nitrogen content in these nitrogen-limited ecosystems. Low-intensity cattle grazing is a suitable measure to reduce the dominance of *T. hybridum*, which in turn provides opportunities for the successful establishment of plant species from the local species pool.

Up to now, only a few non-sown species were able to invade the freshly sown areas. Herbs were underrepresented in the early stage of grassland re-establishment. The majority of the invaders were common and widely distributed grassland and forest species. Tree seedlings, particularly of *Acer pseudoplatanus*, and shrubs (e. g. *Alnus alnobetula*, *Salix myrsinifolia*) were also recorded. On some sown areas, wetland species were present. Furthermore, a few individuals of "weeds" originating from the seed mixture appeared. Some of these are rare and endangered plant species (e. g. *Cyanus segetum*).

A comparison of the floristic similarity of the sown vegetation with that of the surrounding untouched grasslands indicates a low nature conservation value of the sown vegetation, at least in an early stage of grassland re-establishment. The pastures of the *Homogyno alpinae-Nardetum* community are dominated by *Nardus stricta* and harbour approximately 48 vascular plant species within an area of approximately 40 m^2 (WINTER 2005)

In the second year after application, cover of straw layer ranged from 10 to 80 % (mean: 47 %), indicating a very slow decomposition rate resulting from low microbial activity. The effect of straw application on vegetation development was quite low. Presumably, due to the addition of straw some cereals such as barley or triticale and a few weeds appeared. Obviously, certain weed species are also dispersed by straw, increasing species richness on some sites for a short time. On the other hand, a thick straw layer generally prevents both sown and non-sown species from germinating and establishing. Furthermore, due to a wide C:N ratio the addition of straw presumably increases nitrogen deficiency in the substrate. Therefore, straw application to nitrogen-limited ecosystems such as mudflow deposits should be avoided.

The application of farmyard manure to sown areas increased total vegetation cover. Obviously, on bare surfaces a continuous addition of organic matter is of utmost importance for the improvement of environmental conditions, which in turn enhances plant productivity and consequently accelerates initial soil formation. Up to now, liming showed no effect on total vegetation cover, cover of species groups and plant species composition, possibly because nitrogen deficiency in the substrate is the major factor limiting plant growth.

With few exceptions, the current successional stage on the not-sown sites is characterized by a low total vegetation cover. The extreme abiotic site conditions may be responsible for the slow primary succession, whereas competition was not relevant because of the low above- and below-ground phytomass. Some of the present species were typical pioneer plants. Up to now, many of the characteristic species of the surrounding *Homogyno alpinae-Nardetum* community did not establish. Their absence may be linked to their inability to grow on humus-free bare surfaces. In all permanent plots invasive neophytes were missing.

Species diversity at the untouched sites ranged from zero at newly established gravel river banks to 65 at a sandy river bank with dominant *Juncus articulatus* adjacent to a large area covered by a massive layer of deposited timber. Mean species richness was 36 excluding the "zero-plots" with no vegetation. The vegetation was a mixture of species from the mountain pastures, pioneer plants and plants from the riparian forest vegetation (*Alnus incana* forest). The pasture plants have either been swept to these newly established sites or survived at small elevated patches, and where not buried below sand or scree. Sometimes even species from the seed mixture like *T. hybridum* have been swept to the untouched sites. Vegetation cover varied from 0 to 100 %, with a mean of 33 % (without the "zero-plots") and bryophyte cover ranged from 0 to 50 %, with a mean of 11 %. The most common species were *Agrostis capillaris*, *Festuca rubra* agg., *Trifolium repens*, *Ranunculus repens*, *Trifolium pratense*, *Potentilla erecta*, *Lotus corniculatus*, *Achillea millefolium* and *Juncus articulatus*. These species are also common at the mountain pastures; *R. repens* and *J. articulatus* prefer wetter areas alongside the stream. Most of the species are of low nature conservation value as they are common species of the mountain pastures and the riparian forest vegetation. However, these pioneer habitats may be valuable for a range of species (especially animals) that prefer or depend on open areas.

Conclusion

In protected areas, there exist different opinions regarding the decision if re-vegetation measures are necessary. If the rapid re-establishment of pastures is the key goal, re-vegetation measures with site-adapted seed mixtures and farmyard manure applications are necessary for long-term success. In an early stage of grassland re-establishment liming is not necessary and the addition of straw to bare surfaces should be avoided. Extensive cattle grazing on mountain pastures is recommendable if wetlands and areas alongside the river are excluded.

If, on the other hand a high habitat and plant community diversity is the key goal, restoration measures should be avoided. However, one must consider that natural re-vegetation on bare surfaces is a slow process. If the total area of devastated grasslands is small, addition of hay with viable seeds from species of the local flora or transplantation of sods from the surrounding species-rich grasslands may possibly accelerate primary succession in a conservation-friendly manner.

Our findings are representative for siliceous sites in the montane belt of the nature park Sölktäler. Further systematic studies on primary succession and re-vegetation measures in different areas, at different altitudes and on different substrate types are necessary for a more comprehensive evaluation of the initial vegetation development on areas devastated by mudflows. It must be emphasized that our study has been restricted to two years. In addition, the permanent plots next to the stream have been flooded again after the mudflow; these sites are characterized by frequent disturbances. In order to assess the success of different re-vegetation measures more precisely, long-term investigations are necessary. Nevertheless, our preliminary findings can be used for optimizing re-vegetation measures at similar sites both from a nature-conservation and an agricultural point of view.

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