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Open Wounds in Thin Skin: Soil Processes after Natural Disturbances

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Abstract

Natural disturbances are inherent drivers for ecosystem dynamics. Depending on type and severity, effects on soils, in particular on soil carbon dynamics may be pronounced and long lasting. The response is particularly severe in the Calcareous Alps, at sites with shallow Folic Histosols and Rendzic Leptosols. We describe effects of different agents (wind and fire), intensities, and severities of forest disturbance and regeneration patterns on soil carbon cycle at site/plot scale. Comparison of soil carbon stocks along chronosequences of stand replacing disturbances with adjacent stands indicate substantial carbon losses from the organic layer; in particular in case of regeneration slowed down due to ungulate herbivory. Soil CO_2 efflux measurements at a subset of the sites confirm that a temperature driven increase in decomposition of soil organic matter is the main cause of carbon loss from the system after disturbance. CO_2 flux measurements in the turbulent boundary layer of the atmosphere show that even after eight years post disturbance such a site can be a net source of CO_2. Advance regeneration surviving the disturbance retards decomposition and thus soil carbon loss due to its modulating effect on soil temperature. At the extreme end of the studied disturbance severity gradient, we investigated carbon dynamics at a site disturbed by a forest fire in the 1950s. Pronounced differences in feedback between re-establishing vegetation and soil lead to fine scale heterogeneity in soil carbon stocks.

Keywords

Calcareous Alps, forest soil, carbon cycle, CO_2 gas exchange

Introduction

Natural disturbances are inherent drivers for ecosystem dynamics and may occur at different spatial and temporal scales with different intensities (WHITE & JENTSCH 2001). They affect plant communities directly by disrupting ecosystem, community or population structure, as well as indirectly via changing resource availability, i.e. light, water and nutrients (PICKET & WHITE 1985). Soils are an integral part of terrestrial ecosystems and soil biota play an important role for ecosystem functioning. Natural disturbances affect soils in different ways: soil mixing due to forest windthrow or soil erosion at different scales creates regeneration niches. Fire may cause the loss of plant cover and organic soil layers. Pests alter the input of organic matter to the soil. While some disturbances can lead to a fundamental change of the overall site potential, e.g. via erosion, most disturbances, despite causing temporarily increases in resources, may leave the site potential unchanged (WHITE & JENTSCH (2001).

There is a trend towards changing disturbance regimes in European forests, probably related to climatic changes (e.g. SEIDL et al. 2014) as well as to an increased susceptibility of forest ecosystems due to altered structure and composition by previous management (SEIDL et al. 2011).

Soils developed from calcareous substrates, in particular from limestone and dolomite, are particularly sensitive to disturbance (REGER et al. 2015). In many forest areas of the Calcareous Alps historical records and 'silent witnesses' indicate severe soil losses due to former clearcut and grazing activities, also in nowadays protected areas like Nationalpark Kalkalpen (e.g. BAUER 1953).

Depending on the agent of disturbance, bare soil is exposed and prone to erosion. SASS et al. (2012) for example, found up to 200-fold erosion rates at burnt areas in the subalpine belt of the Austrian Calcareous Alps compared to unaffected locations. In such a situation, post fire vegetation regeneration may take 50 to 500 years. Retarded regeneration due to ungulate browsing after large scale windthrow events (PRÖLL et al. 2015) also may exacerbate humus losses (see Fig. 1, results). As Folic Histosols and Rendzic Leptosols consist predominantly of humus, such windthrow-induced changes result in a fundamental alteration of the site potential and have long term feedback effects on the carbon cycle.

In the following, we demonstrate the effects of different types (wind and fire), intensities and severities of forest disturbance and regeneration patterns on the soil carbon cycle at site/plot scale. We focus on forests of the montane and subalpine vegetation belt with shallow Folic Histosols and Rendzic Leptosols. Options for related research in wilderness areas are discussed.

Methods

Study 1: Windthrow effects on post disturbance regeneration and humus dynamics

The pilot study was conducted in order to investigate the effect of stand replacing disturbance (patch size > 1 ha) on natural regeneration and soil carbon dynamics (DARABANT et al. 2009). In each of three regions along a west-east gradient in the Austrian Northern Calcareous Alps (Lechtal Alps, Salzkammergut and Rax/Schneeberg), five to eight sites were selected along a disturbance chronosequence and were compared to adjacent more or less intact mature stands. PRÖLL et al. (2015) provide a detailed description of sites, their disturbance history and the sampling scheme. Soil morphology was described and undisturbed soil samples were taken to the lab for subsequent analysis of the carbon content. At all disturbed patches timber had been harvested and only residual biomass remained.

Study 2: Post-windthrow carbon cycle

In a selected chronosequence of study 1 (Rax) and in an additional chronosequence (Höllengebirge mountain range), soil CO_2 efflux and soil climate were measured in the units stand, gap and disturbed areas of different size and age. A detailed description of the methods is given in MAYER et al. (2014 and 2017a,b). Net ecosystem-atmosphere exchange of CO_2 was measured in the Höllengebirge chronosequence (MATTHEWS et al. 2017).

Study 3: Post fire plant-soil-feedback

At the extreme end of the studied disturbance severity gradient, we investigated carbon dynamics at a site disturbed by a forest fire in the 1950s. KALAS & BERG (2013) described vegetation succession at the fire site. They showed that 60 years post disturbance the vegetation community resembles an alpine grassland. SCHAUFLER (2014) described morphological soil characteristics and determined soil carbon stocks, stratified by vegetation cover (grasses, heather, larch, spruce, mountain pine) and in an undisturbed reference stand. In addition, soil CO_2 efflux and soil climate were measured in the respective units at the disturbed site.

Results & discussion

Study 1: Windthrow effects on post disturbance regeneration and humus dynamics

PRÖLL et al. 2015 found out, that despite high densities of germinants and small seedlings in the forest stands, recruitment establishment frequently failed on both disturbed sites and adjacent stands. Regeneration was insufficient on half of the disturbed sites and regeneration density did not increase with time since disturbance. Ungulate browsing was probably the main cause of regeneration failure. Fig. 1 shows the development of carbon stocks in the organic soil layer of the disturbed sites and adjacent stands.

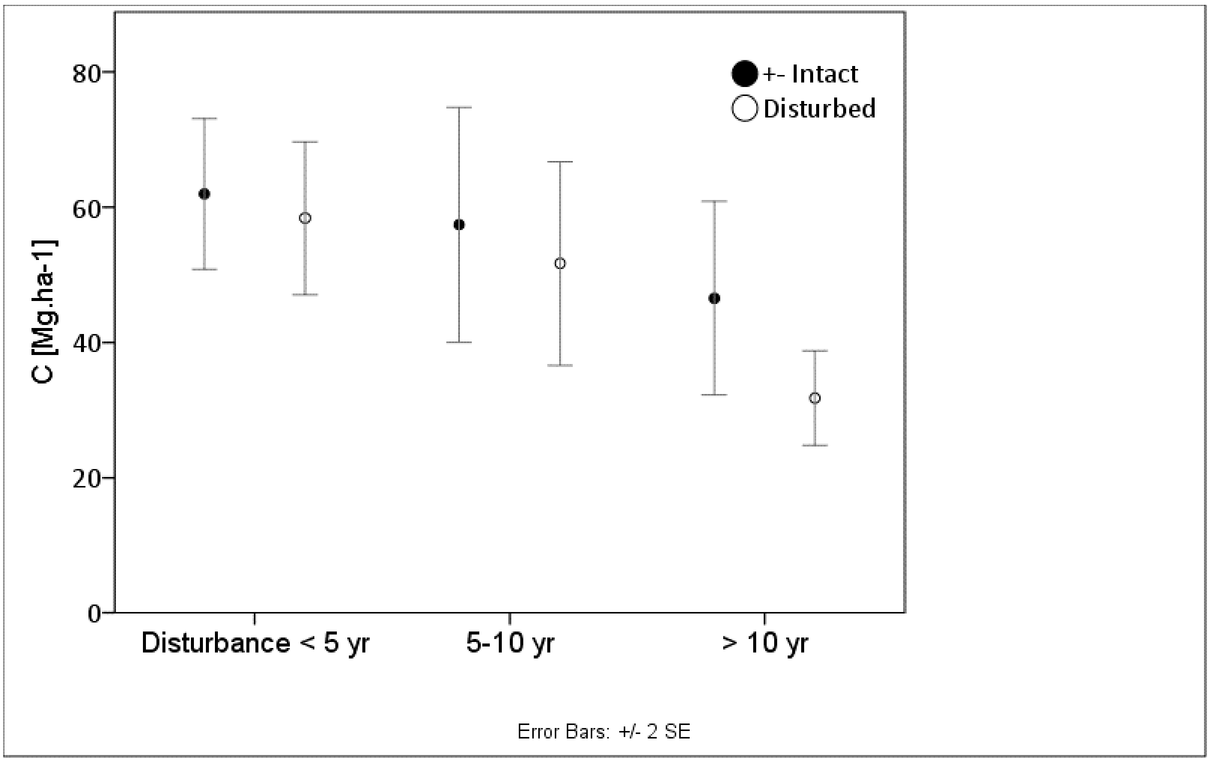

Figure 1: Mean carbon stocks in the forest floor of disturbed sites (different time since disturbance) and in adjacent stands in the Austrian Calcareous Alps.

There is a clear trend of decreasing carbon stocks in the organic layer over time, both at disturbed sites and, less severe in adjacent stands. In folic histosols and rendzic leptosols the organic layer is the main rooting space. Humus losses have therefore severe consequences for water and nutrient supply of the subsequent stands.

Study 2: Post-windthrow carbon cycle

In combination of a chronosequence and a direct time series approach MAYER et al. (2014) found that in the initial phase after windthrow soil respiration did not change compared to undisturbed stands, despite autotrophic respiration was low due to missing vegetation cover. In a later stage, with pronounced regeneration succession, soil respiration at the disturbed site increased significantly. MAYER et al. (2017a) found out that reduced autotrophic respiration at disturbed sites was offset by increased heterotrophic respiration compared to the intact stand. An increase of soil temperature was the main driver for the increase of heterotrophic respiration. The decline of soil organic carbon stocks was in the same order of magnitude as heterotrophic respiration. MATTHEWS et al. (2017) confirmed the negative net carbon balance of the disturbed sites even eight years post disturbance with Eddy covariance measurements. HOLLAUS et al. (2013) also found a substantial increase of bare rock surface and a decrease of soil thickness in the first phase post-windthrow on these south-exposed slope. In a follow-up study MAYER et al. (2017b) could show that established advance tree regeneration retards decomposition and thus post-disturbance C-losses due to its modulating effect on soil temperature.

Study 3: Post fire plant-soil-feedback

With a total of 3.7 kg C m^{-2} (in soil/litter, dead wood, charcoal and root stocks) the soils of recolonized patches at the fire-site have recovered by around 40% in relation to typical site potentials (reference site: 8.4 kg C m^{-2}). Heather shows the highest soil carbon stocks, comprising a total of 5.8 kg C m^{-2} belowground compared to 3.7 kg C m^{-2} for grasses, 3.5 kg C m^{-2} for spruce, 2.8 kg C m^{-2} for mountain pine and 1.8 kg C m^{-2} for larch). Plant-soil-feedback mechanisms are probably responsible for differences in litter input as well as differences in decomposition rates. In lab incubation studies, litter of heather shows lowest decomposition rates under standardized conditions. Soil temperatures and soil moisture in the field are considerable lower and less variable under spruce and heather compared to larch and grass. Less favourable soil climate together with low substrate quality for decomposers are probably responsible for the high soil carbon accumulation under heather and demonstrate its soil regeneration potential.

Figure 2: Vegetation succession in the subalpine belt of the Calcareous Alps 63 years after fire disturbance (©Katzensteiner).

Conclusion and outlook

The studies document the high vulnerability of mountain soils on calcareous bedrock. A projected increase in frequency and intensity of forest disturbances may have detrimental effects on the site potential and on the subsequent forest stands. As biomass was harvested at all of the sites after disturbance, except the one of the fire study, the role of deadwood for post disturbance soil development could not be investigated. In that respect, wilderness areas where deadwood remains after disturbance would provide an option for further research. Plant-soil feedback plays an important role in post-fire soil carbon dynamics.

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