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- Implications for forest management derived from soil ecological studies -

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I Introduction

The present composition and distribution of most central European forests is the result of various impacts by man dating back to the Stone age (HÜTTL et al. 2000). Oak forests were exploited as cattle pastures or as resources for firewood, charcoal burning and tanbark from the fifteenth century on. As a consequence of the short felling cycles (16-20 years), simple oak coppice forests ("Eichen-Niederwald") dominated over other oak forest systems and were widely distributed in the German low mountain ranges during the past centuries (MÜLLER-WILLE, 1980). In the last decades, the economical importance of coppice management has decreased in most of the West-German forest regions so that simple coppice forests have been transformed to high forests, conifer forests or have been left unmanaged (MANZ 1995). As a result, their distribution in the German low mountain ranges tends to decrease and MÜLLER-WILLE (1980) even regards them as a dying forest type. However, the ecological significance of simple oak coppice forests as unique and rare ecosystems is indisputable and has been stressed by many foresters and scientists (HACKER 1983, SCHMIDT 1986, DENZ 1994, POTT 1995).

The importance of gaining knowledge about effects of abiotic and biotic factors on the interrelationships in forest ecosystems is growing (NILSSON et al. 1995). But so far little is known about the abiotic and biotic interactions which determine the stability of simple oak coppice forests in terms of their capacity to return to a norm or "steady-state" following perturbation by man (KHANNA & ULRICH 1991). The stability of forest ecosystems depends, to a high degree, on the functioning of nutrient mobilisation and recycling in the soil (COLE 1995, POWERS et al. 1998).

In a previous study strong indications for forest soil degradation in simple oak coppice forests of the Ahr-Eifel were found (MOHR & TOPP 2001). In extended areas the ground vegetation was totally removed, soil layers mixed and organic soil horizons eroded resulting in reduced contents of several soil nutrients. In view of the observed damages done to the trees by browsing and bark peeling these soil disturbances were mainly attributed to the grazing and trampling activity of red deer which regionally appears in population densities by far surpassing the carrying capacity of the forests.

Preliminary investigations indicated that not only red deer but many other environmental factors may affect soil quality in the investigation area. I hypothesized that the abiotic factors "relief position" and "slope gradient" as well as the biotic factors "wild boar", "stand density" and "stand composition" influence soil degradation in simple oak coppice

forests of the Ahr-Eifel. To test these assumptions four independent field investigations were set up including twelve different forest sites. Soil quality was assessed determining several physical, chemical and biotic soil properties.
The following questions were addressed:

1. Do abiotic factors such as relief position and slope gradient influence soil degradation in the investigation area?
2. Does exclusion of red deer result in an improvement of soil quality?
3. Does soil bioturbation by wild boar grubbing affect soil degradation in simple oak coppice forests?
4. To what extent does a reduced stand density by thinning affect soil properties in oak forests?
5. Which effects on soil characteristics occur when hazel is associated with oak in mixed stands compared to oak-monocultures?

Another main goal of this study was to find out if soil microbial properties are appropriate indicators for soil degradation in the investigation area. Microbial activity, microbial biomass (C_{mic}), metabolic quotient (qCO_2) and the ratio of microbial carbon to soil organic carbon (C_{mic}/C_{org}) have been proposed as indicators for soil quality in many studies and are supposed to constitute an early warning system for soil deterioration (INSAM & DOMSCH 1988, ANDERSON & DOMSCH 1993, BAUHUS et al. 1998, STADDON et al. 1999).
In addition to the field investigations, I conducted microcosm experiments to examine the influence of nutrient availability and substrate quality on microbial characteristics. It was thereby intended to find out if the observed relationships in the field can be reproduced under controlled conditions in the lab.
Three further questions were addressed:

6. Do microbial activity, C_{mic}, qCO_2 and C_{mic}/C_{org} depend on the soil nutrient status and other specific soil properties which determine soil quality in the field?
7. Do microorganisms depend on the nutrient availability under controlled conditions in microcosm-experiments and do the results reflect the relationships found in the field studies?
8. As a conclusion of 6.) and 7.), are microbial properties useful as indicators for soil degradation in sloping oak forests of the Ahr-Eifel?

II Material & methods

II.1 Investigation area

All field studies were conducted in the forestry district Adenau at the Ahr-Eifel (7211), about 60 km south of Cologne (Germany). The Ahr-Eifel is an eastern part of the Eifel-mountains in the Central European low mountain range and is characterized by steep forested hills with elevations up to 700 m above sea level. The dominant wind direction is west to southwest. Mean annual rainfall generally ranges from 600-800 mm and mean annual temperature varies between 6 and 9° C, both depending on elevation and exposure. For climatic conditions in the investigation area during this study see table II.1.

Tab. II.1: Climatic conditions in the investigation area (weather station Nürburg-Barweiler) in the years 2000, 2001 and 2002.

	Mean annual temperature [°C]	Annual rainfall [mm]	Frost days	Dominant wind direction
2000	9.1	762.1	51	W-SW (58 %)
2001	8.6	733	86	W-SW (52%)
2002	9.0	851.2	59	W-SW (49 %)

The parent material is of Devonic origin, mainly slate. Characteristic soil types are acid brown earth and ranker, with a variety of subtypes depending on loess-content, exposure, inclination, vegetation and also degree of degradation.

Oak (*Quercus petraea*) is the dominant tree species in the investigation area. Oak forest are mainly abundant as simple coppice forests which are characterized by clear cutting in regulated areas and the regeneration by stool shoots (BÜRGI 1999). However, coppice management stopped about 70 years ago. Nowadays these forests are not economically relevant. Traditionally, oaks were an important resource of the local industries as firewood, for charcoal burning and tanning. Therefore most of the oaks originate from the stump sprouts and root suckers of harvested trees which is one reason for their stunted growth. At the dry South and South-West exposed hillslopes oak is often associated with pine (*Pinus sylvestris*). Plant-sociologically these forests are categorized as *Hieracio glaucini-*

Quercetum petraea (LOHMEYER 1978). The humid leeward hillslopes are mostly stocked with mixed deciduous forests consisting of oak (*Quercus petraea*), hornbeam (*Carpinus betulus*) and beech (*Fagus sylvatica*) and often associated with other deciduous tree species like ash (Fraxinus excelsior), maple (*Acer pseudoplatanus*), lime (*Tilia cordata*) and cherry (*Prunus avium*). Also present are large areas stocked with Douglas fir (*Pseudotsuga menziesii*) and spruce (*Picea abies*) which were planted strictly for economical use. In the shrub layer of oak forests hazel (*Corylus avellana*), sloe (*Prunus spinosa*), juniper (*Juniperus communis*) and whitethorn (*Crataegus spec.*) are common species.

Another important characteristic in the investigation area is the, at least locally, very high game density. Red deer (*Cervus elaphus* L.) densities were calculated to be at least 20 individuals per 100 hectare which is much higher than documented for most of the semi-natural and natural forests across Europe (2-12 ind./100 ha) (RATCLIFFE 1984, BERTOUILLE & DE CROMBRUGGHE 1995, MAYLE 1996). This high density is maintained by supplemental feeding and a limited culling policy. As a consequence, population densities of the European wild boar (*Sus scrofa*) are also high but there are no reliable calculations yet. The high game density results in visible damage to vegetation and soil. Red deer grazing and trampling and wild boar grubbing destroy the protective ground vegetation, mix soil layers, modify soil structure and change the surface micro-topography in the investigation area. The degree of soil disturbance seems to be dependant on the slope aspect, the slope gradient and the frequency of game occurrence.
The patterns of deer and wild boar activity are diverse and may vary between habitats. Therefore some of the activity patterns of wild boar and red deer that are relevant in the investigation area are described in the following paragraphs:

Patterns of red deer activity

Red deer are not very selective with their feeding preferences and predominantly feed on grasses, herbs, mosses, buds, lichens and shoots or seedlings of shrubs and trees. In the study area a large part of their diet seems to be taken from the shrub and herb layer so that locally both are completely removed. When the protective ground vegetation is missing large herds of red deer (up to 140 individuals) enhance wind and water erosion by trampling, especially at windward sites with high inclinations (HOLTMEIER 1999). Soil disturbance mainly occurs on slopes, where game leave their fixed routes perpendicular to the slope. Particularly susceptible areas have favourable climatic conditions, e.g. sunny sites in wintertime and shady sites on hot summer days which draw large groups of red deer to feed or rest. Moreover, undirected downhill movements of game, either because of escape situations or on the way to a water place or glade, affect the soil profile structure resulting in soil disturbance. It has to be stressed that deer trampling does not provoke soil compaction at sloping sites but rather the disruption of soil aggregates and the displacement of rock fragments. MITCHELL & KIRBY (1990) and REID (1996), with additions from REIMOSER et al. (1999), produced lists of generic indicators of grazing and browsing pressures in woodland. According to this list grazing and browsing was very heavy at all sites of this investigation. Some of the characteristics of very heavy browsing and grazing pressure are: No shrub layer; obvious browse line on mature trees; ground vegetation < 3 cm tall with grasses, mosses or bracken predominating; trampling down of ground flora; extensive patches of bare soil; suppression of growth, and killing of seedling and saplings by browsing soon after germination and, therefore, virtually absent; very abundant dung; bark stripped from trees and from branches on the ground; mosses scarce or absent (see fig. II.1).

Patterns of wild boar grubbing

Wild boars are omnivorous but find the majority of their diet on the soil surface or in the soil. To attain their food they often grub in soil to search for seedlings, saplings, roots, mushrooms and soil invertebrates, both in meadows and forests (fig II.2). Generally, the patterns of grubbing differ from location to location depending on the soil type, the vegetation cover, the food resources, the season and the herd size (WELANDER 2000). Rooting may be superficial, affecting only the litter layer, or detrimental, breaking through the surface layer of vegetation and excavate soil to a depth typically ranging between 5 and 15 cm (KOTANEN 1995, GROOT BRUINDERINK & HAZEBROEK 1996). This often includes the mixing of organic topsoil with mineral soil. The displaced vegetation and soil may be left in place or moved aside burying untouched vegetation or forming mounds. The area grubbed sometimes extends for more than a hectare or is just composed of many small (~1 m²), overlapping disturbed patches ("feeding stations" – VALLENTINE 1990). In the investigation area wild boar grubbing is rarely superficial and in the most cases includes the excavation of soil and the mixing of soil horizons. Uprooting and feeding on seedlings constitutes a direct effect on trees. According to the local foresters in some areas wild boars turn over the forest soil about 3 to 4 times a year.

Fig. II.1: Typical phenotype of soils in simple oak coppice forests confronted to very heavy browsing and grazing pressure by red deer.

Fig. II.2: Extensive soil bioturbation by wild boar grubbing in a simple oak coppice forest of the Ahr-Eifel.

II.2 Investigations – design and site description

This study includes four complementary investigations to test for the influence of several abiotic (slope aspect, slope gradient, relief position) and biotic factors (deer, wild boar, stand density, plant species composition) on soil degradation in simple oak coppice forests of the Ahr-Eifel. In these four investigations soil properties of 12 different forest sites were studied. For the investigations II, III and IV the forest sites were split into experimental plots to test the effects of different treatments under the same site conditions.

In a fifth approach microbial properties (microbial activity/biomass, qCO_2 and C_{mic}/C_{org}-ratio) were correlated with selected soil properties from the investigations I-IV to evaluate the significance of microbial properties as indicators for soil degradation in simple oak coppice forests. The selected soil properties were soil pH, maximum water retention capacity (WRC_{max}), ratio of organic carbon to total nitrogen (C/N) and the contents of organic carbon (C_{org}), total nitrogen (N_t) and phosphate-P (PO_4^{3-}-P) Additionally, microcosm experiments were conducted to study the influence of substrate quantity and quality on microbial characteristics under controlled lab-conditions.

II.2.1 Investigation I (relief position)

Eight forest sites were sampled to evaluate the effects of the abiotic factors slope aspect (windward/leeward) and slope position (plateau/ upper slope/lower slope/foot slope) on selected physical and chemical soil properties of simple oak coppice forests.

All sites were similar in soil forming bedrock, plant species composition, elevation and slope gradient but differed in exposure. Four were windward-exposed, the other four were leeward-exposed (fig. II.3). Dominant tree species was oak (*Quercus petraea*) and soil types were acid brown earth, acid brown earth ranker and ranker. For more site characteristics see table II.2.

Soil pH and the contents of potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and aluminium (Al^{3+}) were monitored at all sites in July 1999, October 2001, May 2002 and October 2002 with a replicate number of n = 8. Microbial characteristics (activity, C_{mic}) and the contents of organic carbon, total nitrogen and phosphate-P were only measured in July 1999. These data are shown in the Appendix (tab. Appendix-1.3) and were used for correlation and regression analyses (see II.2.5).