STUDIA UBB GEOGRAPHIA, LXIV, 2, 2019 (p. 17-60)
(RECOMMENDED CITATION)
DOI:10.24193/subbgeogr.2019.2.01

FIRE ON THE MOUNTAIN. DISTURBANCE AND REGENERATION IN DECIDUOUS AND CONIFER FORESTS. 20 YEARS OF EXPERIENCE

ERHARD SCHULZ[1], HUSSEIN ALMOHAMAD[2], ATTILA BENCSIK[3], HOREA CACOVEAN[4], MATHIAS HALL[5]

ABSTRACT. Fire on the Mountain. Disturbance and Regeneration in Deciduous and Conifer Forests. 20 Years of Experience. Two test and monitoring sites in SW Germany (Forchtenberg) and Leghia (NW Romania) furnish insights to the regeneration modes after fire, clearing, burning, and cultivation -slash and burn - in a deciduous forest or after wildfire in a conifer stand. Forest maps and archivalia helped to reconstruct the forest history of the last 250 years of the Forchtenberg site, which as a heritage still influences the present situation. We could document the autonomous co- evolution of vegetation and soil over two decades. It was done by transects and mapping as well as by soil analysis and micromorphology. The role of soil animals for the weathering of charcoals became evident. The evolution of vegetation and soil after a wildfire could be studied on the Leghia site and compared with the Forchtenberg results. As the Leghia site was not cleared after the fire, it enabled us to follow the stages of decay and of regeneration, where conifers do not play a role. Moreover, one could investigate the effects of grass- and pasture fire, still active in the region. It also evidenced the necessary differentiation of charred material into wood- and grass coal. The indicator values of topsoil/soil surfaces are presented as well as those of charred material for the regeneration stages. Finally, we will discuss the fire risk in deciduous forests under a changing climate.

Keywords: *Forest disturbance, succession types, forest history, slash and burn, wild fire, charcoal taphonomy, fire risk.*

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[1] *Institut für Geographie und Geologie, Universität Würzburg, Germany, e-mail: erhard.schulz@mail.uni-wuerzburg.de*

[2] *Department of Geography, Quassim University, Saudi Arabia, e-mail: H.Almohamad@qu.edu.sa*

[3] *Department of Mineralogy, Geochemistry and Petrology, University of Szeged, Hungary, e-mail: bencsika@u.szeged.hu*

[4] *Office for Pedologic and Agrochemical Studies, 400483 Cluj-Napoca, Romania, e-mail: turda75@yahoo.com*

[5] *Landratsamt Hohenlohe, Forstamt.74643 Künzelsau, e-mail: Mathias.hall@hohenlohekreis.de*

1. INTRODUCTION

Slash and burn is a widely discussed item in archaeology and landscape history (see Jacomet et al. 2017, Rösch et al. 2017). It mainly turns around the question, whether a shifting economy or a permanent cultivation could be an adapted model for the Late Neolithic. However, regeneration modes and their duration after heavy disturbance became an important topic with the reinstallation of a coppice system in Bavaria (Ewald et al. 2018) and the discussion, whether these exploitation systems would be more adapted to the changing ecological and climatic conditions than the high canopy forest systems. Moreover, fire and fire risk got important in temperate regions during the last years.

Two test sites will serve for information on these topics. The one is the long-time Forchtenberg experiment (Rösch et al. 2011, Schulz et al. 2014), in SW Germany and the other is the wildfire site at Leghia/NW-Romania (Schulz 2017). For both sites the main questions are: which are the pathways of regeneration of vegetation and soil after severe disturbance such as fire and how many years it will take? In addition, what are future risks out of a changing climate? To answer these questions, the regeneration is documented for vegetation and soil. This was done regularly by mapping and by physiognomic transects. Maps were established in parallel for the soil and plant cover. They serve to establish time series and to explore the types of evolution. Investigation on soil concentrates on topsoil/ soil surfaces and it is basic structure and micromorphology. This is equally valid for the question of charcoal types and evolution in their dependence on soil animals. The question of a rising fire risk in deciduous forests will be discussed too on the background of a changing climate.

2. THE TWO TEST SITES AND THEIR PHYSICAL CONDITIONS

Both sites are situated in temperate forests of Central Europe and they are part of old cultural landscapes. The aim of these investigations is to explore the chances of the slash and burn-model to explain the Late Neolithic economy for the one and to elucidate the pathways of regeneration of vegetation and soil after sever disturbance in a forest environment, where fire plays and important role.

2.1. The Forchtenberg experiment. A general description

It is since 1997 that near the town of Forchtenberg up the Kocher valley/ SW Germany (49° 37´N 10°15´E) a 3.5 ha forest plot served for a long-time experiment on slash and burn and the following successions of vegetation and soil (see figure 2). It belongs to the Forest Authority of Hohenlohe-formerly Schöntal and it was placed at our disposal in 1997 for a period of about 20 years (Rösch et al 2011). However, the work will continue.

2.1. The double direction of the experiment

This comprises:

A: Clearing, burning and cultivation in order to have an idea on possible yields to be interpreted for the Late Neolithic landscape management (Rösch et al. 2017, Schier 2009, 2017). The yields in the first year of cultivation were astonishingly high - up to 40 dzt/ha (Ehrmann 2009, 2014) but they decreased dramatically in the following years. This strongly indicated the necessity of rotation or shifting cultivation even if this topic is disputed again in recent times (Jacomet et al. 2016, Rösch et al. 2017).

B: A survey of regeneration pathways of vegetation and soil after the end of the cultivation period. It is the main object of this article. This also will give ideas to interpret former landscape development and provide indicators in soil for human interference especially for fire conditions and for the taphonomy of charred material.

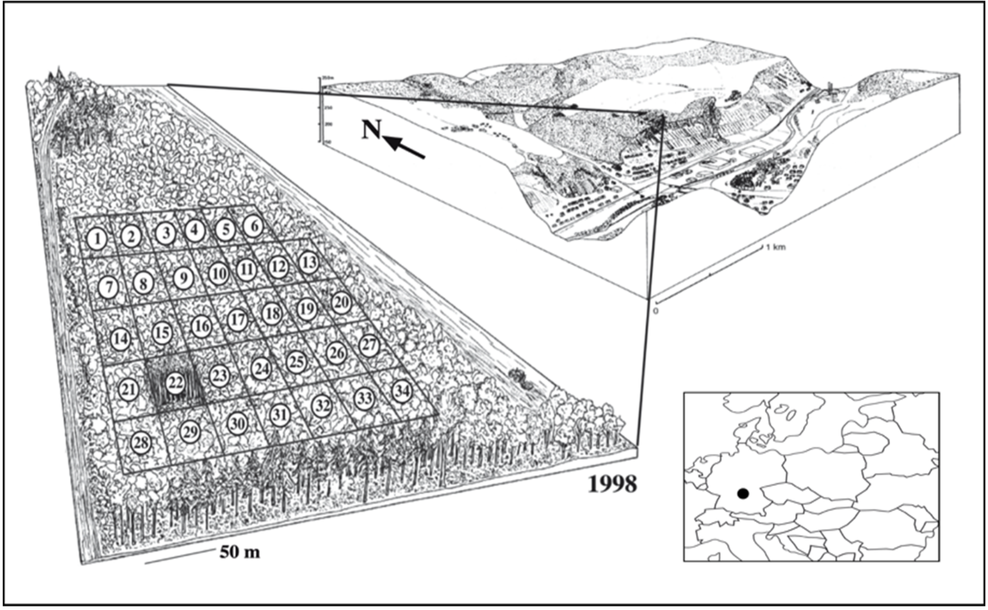

Fig. 1. The location and compartimentation of the Forchtenberg test site up the Kocher valley / SW Germany (from Schulz 2017, modified).

2.2 The physical situation of the test site

The physical situation is described by figures 1 and 2. The test site is situated on the Hohenlohe-Plain, which evolved on a layer of siltstones of Upper Triassic age covering massive banks of Middle Triassic limestone. Soils have developed from an approximately 1 m - thick loess cover. They mostly belong to Luvisols and Cambisols. Stagnic features are common.

Mean annual precipitation is about 850 mm with a mean annual temperature of 8.9°C (Hermann et al. 2007). The forest mainly consists of 40 to 60 years old beech as well as oak, maple, ash, and others.

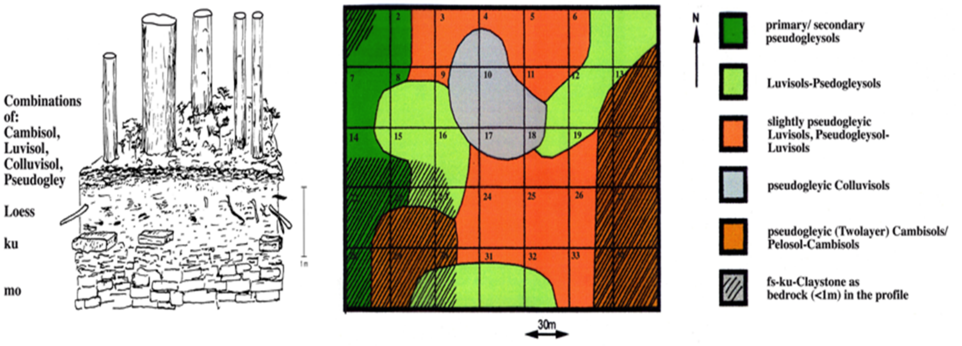

Fig. 2. The physical conditions of the Forchtenberg-test site; geology and pedology (from Schulz 2017, Herrmann et al. 2007, modified).

4. The Leghia wild fire site. A comparison site to the Forchtenberg experiment

It is near the village Leghia in western Transylvania / Romania (46°52´N 23°12´E) where investigations on the evolution of vegetation a soil after a "wild" fire in 2011 could start in 2014 (see figure 3). The site takes a part of the cuesta of tertiary (Eocene) lime-, sand- and clay-stones north of the Nadăș Valley, which goes parallel to the Someș River (Cacovean et al. 2016). The cuesta also got famous for its gypsum exploitation (Husu 1999).

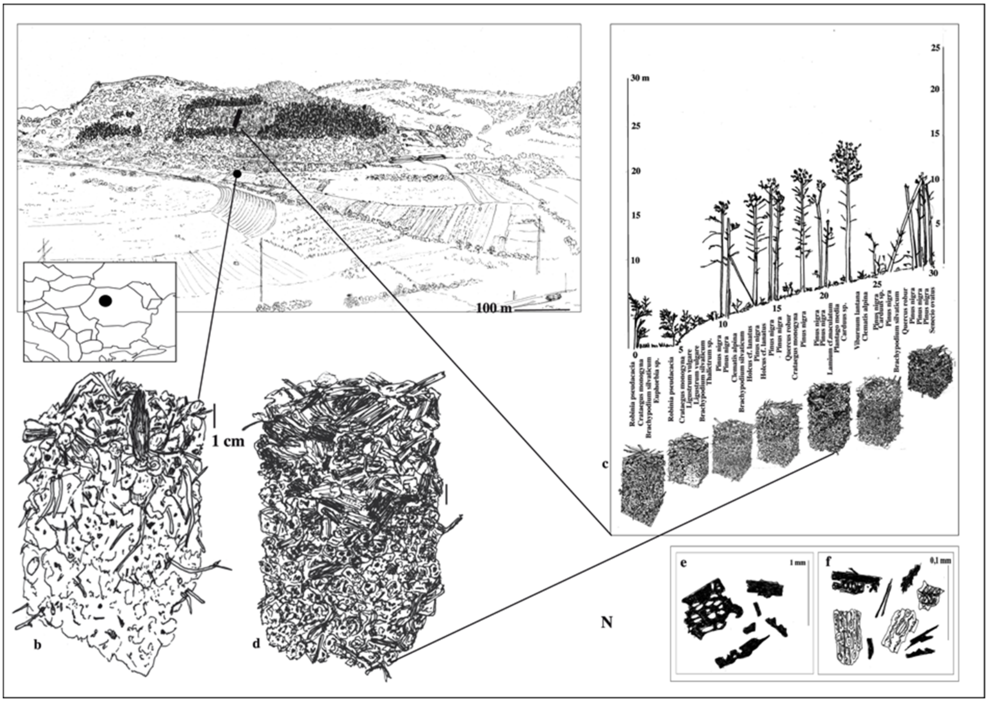

Fig. 3. Overview of the Leghia escarpment in NW Romania. It shows the forest fire site in the *Pinus* plantation, the topsoils of a burned pasture and moder with in the *Pinus*-stands and a combined transect on the lower slope of the wild fireplace. It also demonstrates the difference between wood-coal and grass-coal.

The region is intensively exploited for wheat, corn or potatoes as well as for meadows and sheep pasture. It has a subcontinental climate with about 600 mm precipitation but a highly contrasted seasonality. Originally the slopes of the cuesta were covered with deciduous forests -*Acer-, Quercus*- or *Fagus*- (Coldea 2015) but heavily overexploited during time. The slopes were often afforested with Pine trees, in the 1960s. Soil cover is very shallow and belongs to calcaric regosols.

One of these forest plots took fire in august 2011. There were some attempts to extinct the fire but afterwards the site remained more or less untouched.

The Leghia site enabled us to compare the vegetation-soil-regeneration in a deciduous forest with that of a conifer forest. The investigations consisted of transects of vegetation and soil, pedology and micromorphology.

3. METHODS

Investigation work comprised both the physical work to prepare the sites as well as the different methods of documentation.

3.1. The physical work

The Forchtenberg test site was divided into 34 plots each of 30 x 30m (see figure 1). Slash and burn comprised to clear on plot in winter and remove all wood larger than 10 cm diameter. The rest remained to dry until the next fall. Branches and twigs are collected to a 1m high roll. It was enflamed by glowing charcoals and was pulled over the surface of the respected plot. Wheat was sawn in the ash layer. It was harvested in the next summer. Cultivation was repeated one or two times. Afterwards the plot was abandoned and a next plot was chosen for the experiment. Thus, a series of different stages of regeneration characterised the test site after some years (see Erhmann et al. 2009, Schulz et al. 2014, figure 4).

Fig. 4. The threefold work of slash and burn (from Schulz et al. 2014). It comprises clearing in winter, drying in the summer, burning in fall, and cultivation for some years.

3.2. Documentation

The abandoned plots were documented for their evolution of plant- and soil cover. This was done by mapping of vegetation and soil and by transects in order to give an image of the third dimension.

The principle of mapping is the documentation of soil cover of single plants- in the limits of scale 1:50. The presentation, however, is done in physiognomic terms (trees, shrubs, dwarf shrubs, high forbs, herbs, grasses, mosses). After the first cycle of forest development- to a high coppice - we changed the presentation and the crown cover of trees is given now transparently and colour rings indicate the genera. The lower vegetation is still presented by physiognomy only. In case single surface is too small, a mosaic is announced for the respective surface.

Soil is mapped by using the soil surface/topsoil as main indicators for the regeneration stages. They belong to the most sensitive systems to environmental changes. An inventory of soil surfaces (figure 5) shows types of a rapid mineral organisation (bare surfaces) and several stages of biological colonisation including “Pellicular Organisation Types” (Pomel 2008) or “Biological Soil Crusts” (Belnap et al 2001, Ullmann and Büdel, 2001, Weber et al. 2016). These soil surface types are indicators for their ecological conditions and, thus, considered as “functional surface cover types” Buis et al. 2009). Clay sealing is a first and rapid organisation fixing and stabilising a new mineral surface within days. Bacteria- and algae- films represent the first stage of biological colonisation, which may be followed by mosses, grasses or herbs coming either from a seed bank or from external transport. Grass felt may develop to thick layers and hamper a colonisation of tree seedling for long time. They evolve within months. Leaf layers indicate a bush or forest environment with a varying activity of earthworms and other decomposers. Crumbly mineral surfaces point to a very intensive decomposition, whereas an O_h-layer is a sign of a very slow mineralisation of organic matter. Splinters and charcoal are additional types, the latter indicating fire. Mostly-as vegetation types do- these surface types occur in mosaics too. Besides mapping structure, samples were collected at selected sites. They were analysed under the binocular and samples were chosen for thin sections. These served to analyse microstructure and to document the different interferences of soil animals. Thus, the soil samples were not destroyed in order to isolate the soil animals. Those were recognized under the binocular as main groups as well as for their droppings in the thin sections.

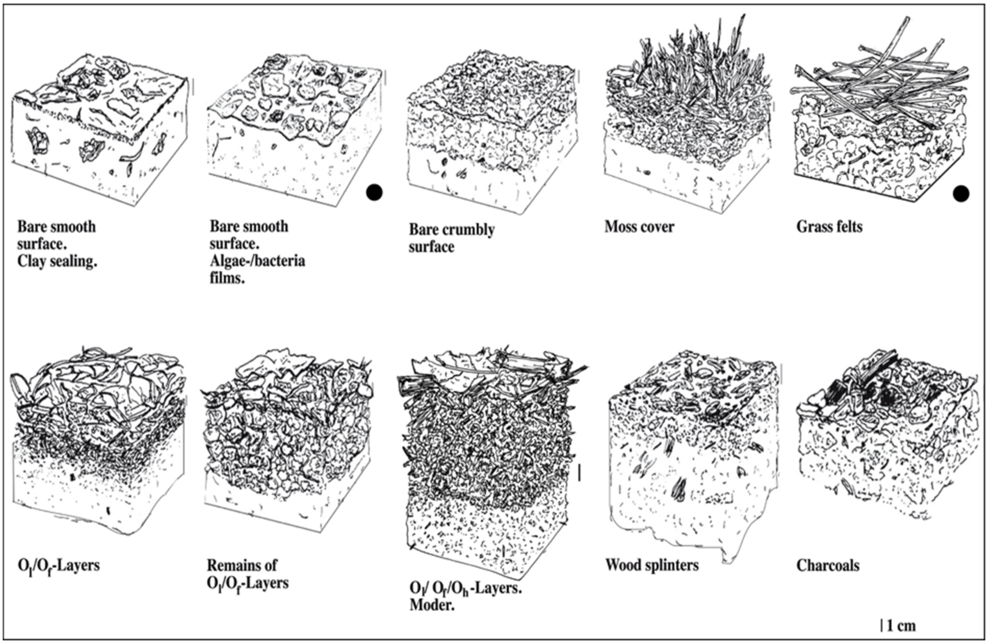

Fig. 5. Topsoil/ soil surfaces as indicators for the regeneration stages. It shows the three stages of rapid surface closing, the settlement during months, and the long-time development of leaf layers

As mentioned above, transects were taken for each plot along the middle line at 15 m West-East in order to give an idea of the physiognomy of vegetation. Each 5 m a structure sample for topsoil was taken too. Together with the maps these transects will give a better idea of the respective plots (see figure 8).

4. DISTURBANCE AND REGENERATION AT THE FORCHTENBERG SITE. THE LONG FOREST HISTORY IN DIFFERENT PHASES

Forest development and succession stages are of different scales. For the one the short-time cycles develop in decades and for the other the evolution to mature forest takes centuries. Thus, it was necessary to elucidate the long history of the actual test site in order to know about the role of its heritage.

4.1. The forest history of the last centuries (figure 6)

A graphical reconstruction of the last 250 years was based on the interpretation of natural relicts such as old pasture trees, on dendrochronology, on forest maps of 1949, 1970, 1982, and 1992 and on archivalia of the house of Hohenlohe–Öhringen (Beutler 1988). It is paralleled to the general landscape history (Saenger 1957). Four different periods could be discriminated.

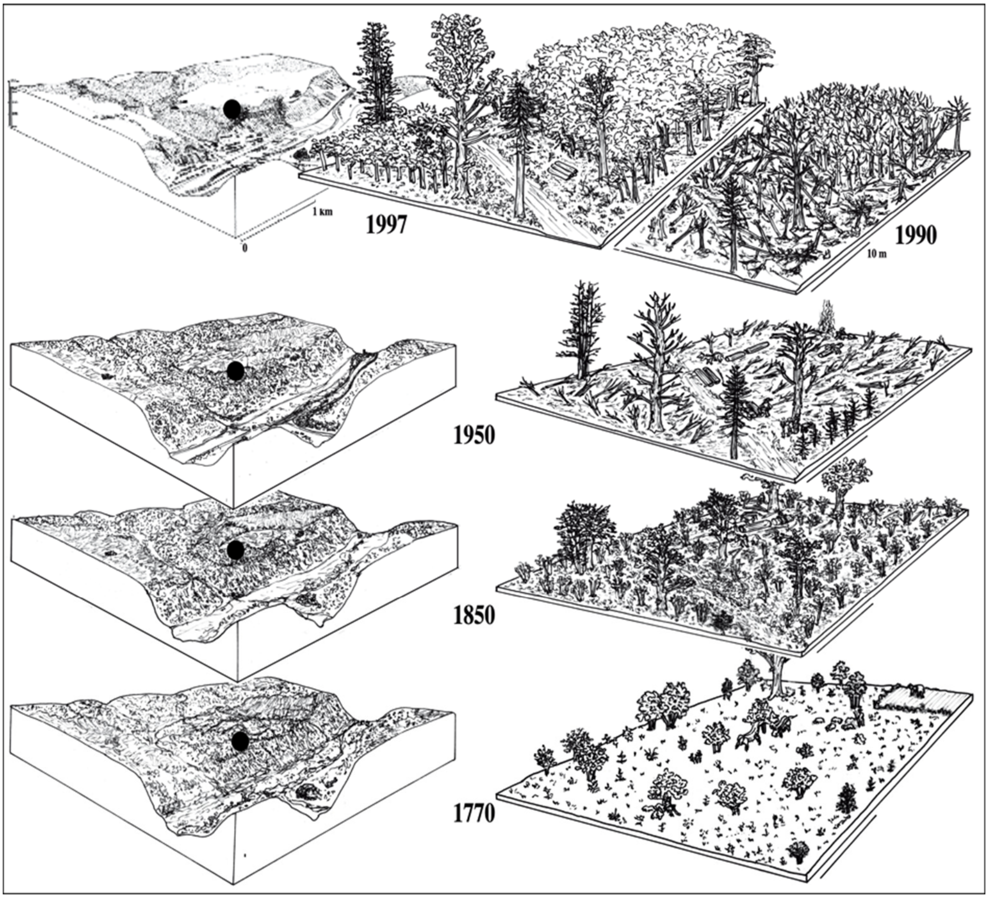

Fig. 6. The reconstruction of the 250-years landscape- and forest history of the Forchtenberg-test site.

A: The anarchic forest exploitation

It was typical for the 18th century. The landscape was characterised by small-scale fields within the three-field-rotation system. The steep slope had wine cultivation and the alluvial plain was used for pasture. The forest saw irregular clearings, pasture and short-time agriculture. Wood cutting and coppicing were often and resulted into a coppice / tailis / Niederwald and an open sheep pasture. The trees were maple, ash, and hornbeam together with roses and blackberry bushes.

B: The regular forest exploitation

The time of the 19th century up to the middle of the 20th century was still dominated by the small-scale fields in a rotation system. Wine cultivation on the slopes diminished and the alluvial plain was stepwise settled by some industrial plants. The settlements enlarged, and there also was a train up to Forchtenberg town until the 1960s.

At 1805 the forest came under the authority of the House of Öhringen and was transformed into the dual system of coppice with standards / tailis–sous-futaile/ Niederwald with a composition of 70% beech, 25% oak, and hornbeam, maple, or cherry.

C: The modern forest exploitation

The forest was stepwise transformed into the “modern” system of high canopy forest /futaile regulière/ Hochwald by plantation of conifers. However, it got several areas with a composition of 20% beech, 20% fir, 20% pine, 10% larch and 30% of maple, ash, and hornbeam, whereas the greater part of the forest was still dominated by deciduous trees. In the mid-1960s the landscape was characterised by large fields after rearrangements, the replanting of wine on the slopes and the growing settlements. The forest passed to the Schöntal-Forest Authority. It was cleared and replanted with 30% beech, 20% oak and some ash, hornbeam and cherry. In 1990, after the damages of hurricane “Wiebke”, afforestation was done by 30% of beech, 20% maple and some ash, hornbeam, and cherry.

D: The actual forest economy

The present directive of the Hohenlohe –Forest Authority is focussed on the maintenance of the floristic composition. It also is the intention to hold mixed stands both in composition as in age. When the older stage of trees is classified as having reached its economic maximum it will be taken out. However, an autonomous “natural” rejuvenation is appreciated. If there is not a sufficient understory, young trees must be planted. At any case, large free spaces, such as after complete clearing, should be avoided. However, in case of thunderstorms or large bark beetle attacks it will be necessary to intervene in order to reach the directives. In all, the forest authorities should follow an economic goal (wood production, holding of reserves) as well as to preserve ecological conditions (water, soil, air quality) or recreation items.

In 1997 a 3.5 ha area was passed to the experiment and from that time on there is the chance to follow the traits of autonomous rejuvenation.

4.2. The short- and medium-time regeneration after disturbance. The first cycle (figure 7)

The slash-and-burn experiment (see above) provided chances to follow the evolution pathways apart of the forest authority directives and their restrictions.

The activities and processes within the experiment comprised clear-cut of the respective plot – complete or incomplete, high- and low-temperature burning, and cultivation with restrictive tillage (see figure 4). Thus, the first two or three years saw various impacts on each plot, which highly disturbed/ destroyed the plant covers, and the upper soil material.

The recovering steps of vegetation and soil after clearing burning and cultivation are explained by the evolution of the plot FOP 15 (FOP: Forchtenberg Plot. For location see fig. 2). The plot shows the classical forest evolution and will be preserved for long time observation as comparison plot within the experiment. Clearing was in winter 1998/1999 and the plot was abandoned after the end of cultivation in 2000. The different regeneration stages are presented both for vegetation and soil surfaces. The first map (1999) shows the situation in summer after clearing but before burning. The surface was rapidly colonised by grasses, high forbs and *Rubus*- shrubs, but large parts still remained unsettled. Soil surfaces depict the heritage of the forest (Ol/Of and its remains) as well as the dominance of the grass felts. The southern part is a forest track, which always showed its own dynamic.

One year later (2000), the plot shows an interfingering of grasses, shrubs (mostly *Rubus*), high forbs – confined to the burned field – and some mosses. Still some small areas remained uncolonized. Soil surfaces depict the burned field by charcoals and mosses. The grass lobe colonising in the Southwest is obvious and it will be visible the following years. The areas of leaf layers demonstrate the forest heritage as well as the shrub evolution. 2001 marks the change to uniformity by the dominance of the shrub-tussock grass (*Rubus-Deschampsia*) unit and the resprouting from stumps. The burned field is still marked by high forbs. Soil surfaces clearly indicate the burned field by charcoals. Mosses prevail under the *Rubus-Deschampsia*-units, which also support the earthworm activity visible by the bare crumbly surface

Five years after clearing (2004) the plot gets more and more uniform. The *Rubus-Deschanmpsia* units prevail but several shrubs – either from seedlings or from stumps – developed into trees. In soil surfaces leaf layers already dominated together with mosses and grass felts. Charcoals however are completely covered by leaf layers, mosses and grass felts too.

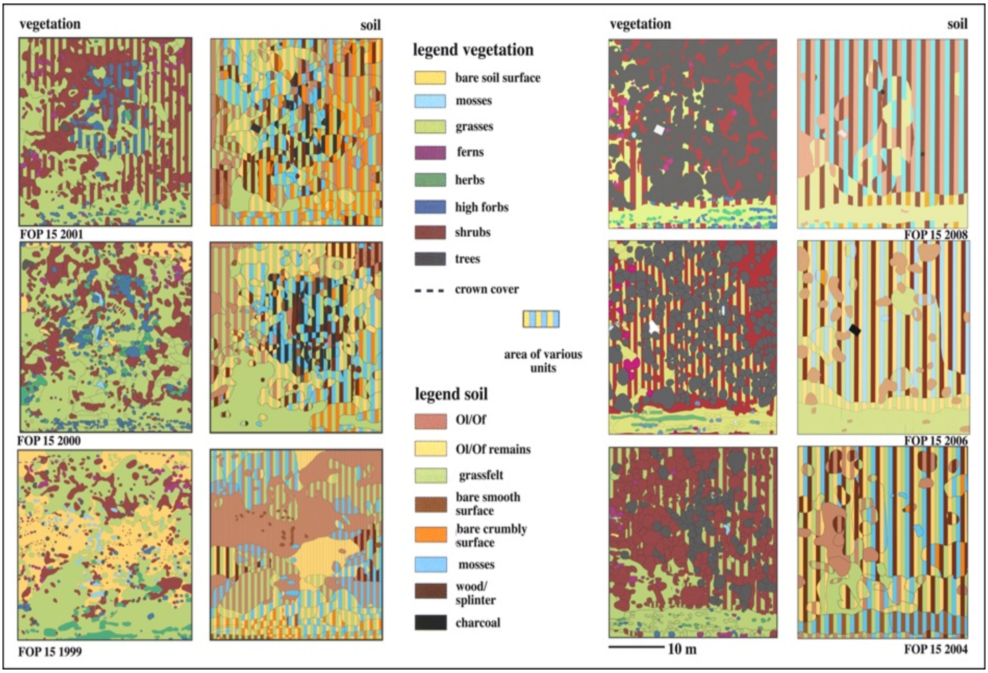

Fig. 7. Maps of vegetation and soil of FOP 15 showing the first stages of regeneration and those of early development to a coppice. Finally, the way from diversity to uniformity.

The further development (2006 and 2008) is characterised by the growing of the tree cover. Shrubs restrict grasses more and more - mostly by *Rubus*. The soil surfaces are dominated by the combination of leaf layers, splinters and mosses. Also, the forest track is clearly visible.

Thus, this series of maps depicts the development of the first and second mosaic of recovery. The first represent the evolution of a clearing flora until it is partly destroyed by burning and afterwards incorporated into the second mosaic of shrub and forest recovery into a uniformity of a young coppice. The grass lobe in the Southwest shows, that the first colonisation step may remain visible for long time.

The plot developed to an individual and species rich forest, much more diversified than the previous forest. The process was a mixture of seedlings arrived by wind and animals, continuous growing of seedlings or sprouting already present under the former forest cover and by resprouting of stubs – especially maple, hornbeam and beech. At present it is in a state of rapid growing, high density of individuals and also a high rate of dieback.

4.3. The second cycle. Recovering after the second clearing, burning, and cultivation

Four plots were chosen for their indicator value of each plot in the succession state. Two of them are characterised by middle or late succession states (FOP15 and FOP22) whereas FOP14 and 21 were cleared recently (14.3.2017, 21.1.2015). Therefore, they demonstrate the initial or younger states of regeneration. Moreover, the plots FOP 15 and FOP22 were cleared completely, in opposite to FOP 14 and FOP 21, which – out of logistic reasons – were only cleared for their central parts. Thus, it will be visible in the different stages of succession (figures 9 and 10; for location, see figure 2).

Transects of FOP 14, FOP 15, FOP 21, FOP 22 were made in order to give the physical aspects of vegetation and soil. Mapping followed the Forchtenberg protocol (s.a.), however, we enlarged the information content. As the tree cover of FOP 15 got almost closed it was useful to specify the tree genera by coloured rings.

4.3.1. Transects on FOP 14, FOP15, FOP 21, FOP 22 (Figure 8)

Transects are taken along the middle line from West to East of each plot together with structure sampling each five meters. They shall give the physical aspect of the plant and soil cover of the respective plots.

FOP14 is the youngest plot. It was cleared again in winter 2016/17, however not completely. Thus, the edges are settled with old trees. Grasses and ferns dominate the centre. It is visible by the soil structure as in the centre grass felts dominate. By chance, charcoals from the first cultivation were preserved at two places. It was by the dominance of enchytraeids in these parts.

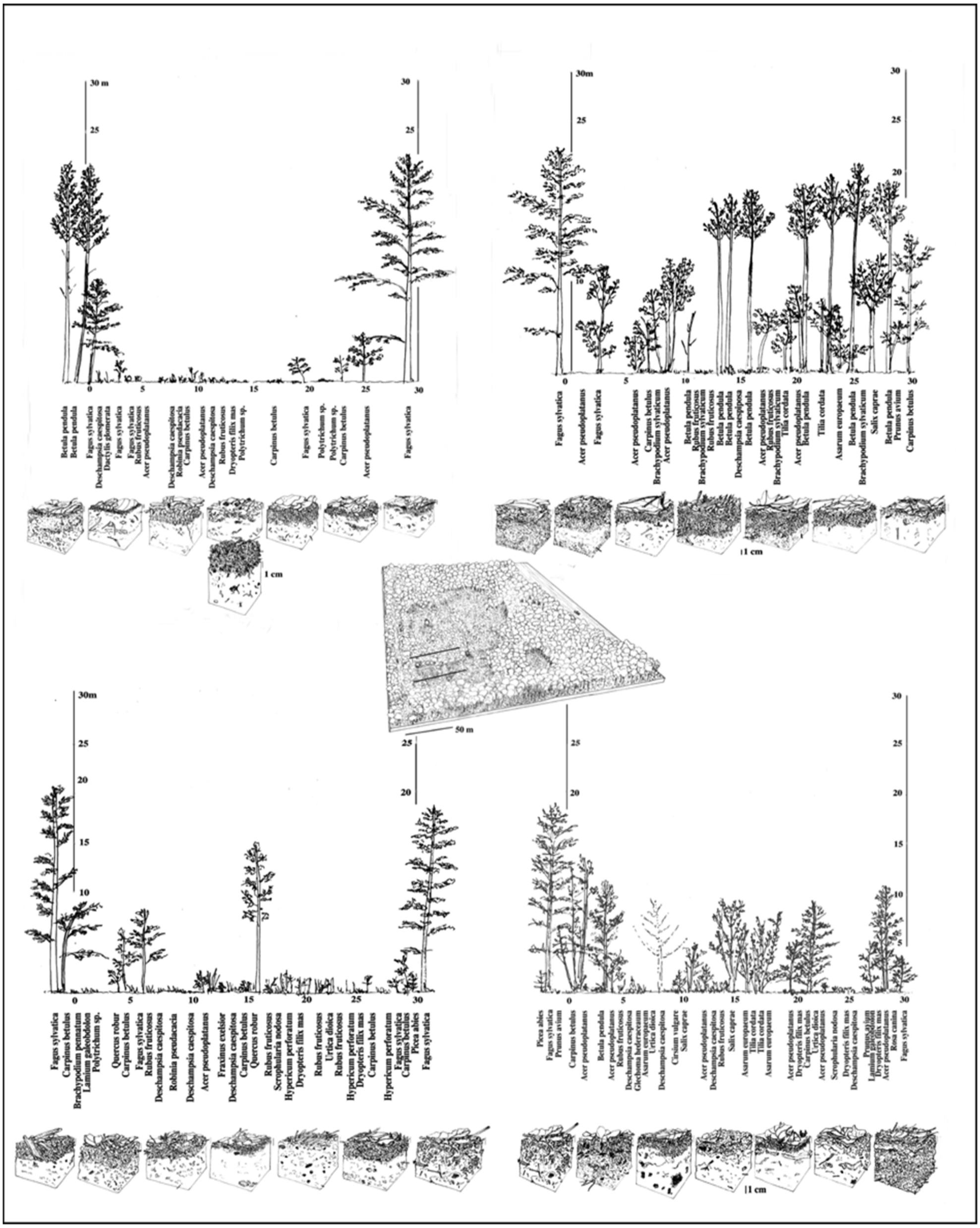

Fig. 8. Transects for vegetation and soil structure. FOP 14, FOP 15, FOP 21, FOP 22 – for location see figure 2.

FOP 14 and FOP 21 represent the early stages of regeneration clearing, whereas FOP 15 shows a young coppice 18 years after clearing. FOP 22 indicates a medium stage 10 years after the second clearing within the rotation system of slash and burn.

FOP 15 represents now a high coppice with an undershrub mostly by resprouting maple or hornbeam. Leaf layers dominate the topsoil (see above).

FOP 21 was incompletely cleared again in winter 2014/15. By now, the plot is divided into a forest and in a grass part, as the structure samples depict by leaf layers or grass felts. Obviously, the charcoals present at 20 m indicate the old burning and cultivation zone

FOP 22 was cleared again in 2007 as the first plot for the rotation system. At present, it shows the aspect of an intermediate stage of regeneration with the dominance of young trees and shrubs. At 5 and 10 m the recent and older cultivation is visible by different position of charcoal in the structure samples.

4.3.2. The new vegetation and soil maps (Figures 9 and 10)

The first group comprises the young succession stages (Figure 9).

FOP 14: This plot developed to a mosaic of grass, ferns and some shrubs – mainly *Rubus.* The southern part – the forest track – reacted differently. It shows the grass cover and only some new seedlings of *Rubus* and *Carpinus*. The plot itself depicts two types of heritage: an old one prior to the 1990s, which is shown by groups of big trees, *Fagus* in the Southeast and *Acer* in the western part. The rectangular moss cover in the eastern part points to a fallen old tree in the storm of 1990. A younger heritage is present as regrown after the first clearing in winter 2001/2002, which excluded the eastern rim and the *Fagus-Carpinus* group in the Southeast. This concerns the trees in the northern part of the plot.

The surface was burned twice in spring and fall 2002 and after cultivation it was abandoned in 2003. It was on that plot that an old birch tree was set free in 2001. From that time on, birches colonised free spaces on the whole test area. On FOP 14 it is visible in the north-eastern edge. Comparable to those colonising is the presence of a single *Populus* tree. *Salix caprae* is an early and singular coloniser too.

FOP 14 also shows the heritage areas of trees, which are characterised by the mixture of Ol/Of and splinter. The remnant leaf layers are mixed with grass felts in the centre. Mosses are scattered, they also indicate an old wind fall. At some rare places the surface got bare and show either the bare surface type or expose the old generation of charcoals near surface, concentrated by enchytraeids or mites. The forest track in the South depicts grass felts, which are mixed in the Southwest with Ol/Of remains of mosses under the tree umbrella.

FOP 21. The plot was cleared for the first time in winter 1999/2000. The clearing was complete with the exception of some single oak and cherry trees.

They represent now an old heritage from the 1990s. Burning was done in spring and fall 2000. After cultivation on different places the plot was abandoned in 2001. In winter 2014 the plot was cleared again, however, it was done only in the centre, which created a younger heritage of tree cover in the West, the South and in the East. Burning took place in fall 2015 and cultivation was in summer 2016. The plot shows a picture comparable to that of plot 14. The herb and grass cover started to develop on the cleared surface. The area under the tree cover remained almost free. Mosses are more important than on plot FOP 14. Some single old trees dominate the free space, among them also a *Betula* group. Interesting enough, invaders could settle to that plot such as *Robinia*, which established from several seedlings and also have two generations yet. A single and small *Picea* exemplar only survived under the umbrella of an old *Fagus* tree at the eastern rim. At present it is dead due to the drought of 2018. Among the herb invaders there are only *Solidago* and *Erigeron*. The high forbs are scattered in the southern half of the parcel. They are *Scrophularia, Eupatorium, Epilobium* and *Hypericum*. The eastern part of the centre shows the cultivation area, which got invaded by *Deschampsia* and *Rubus* after harvest, which could completely cover the charcoals.

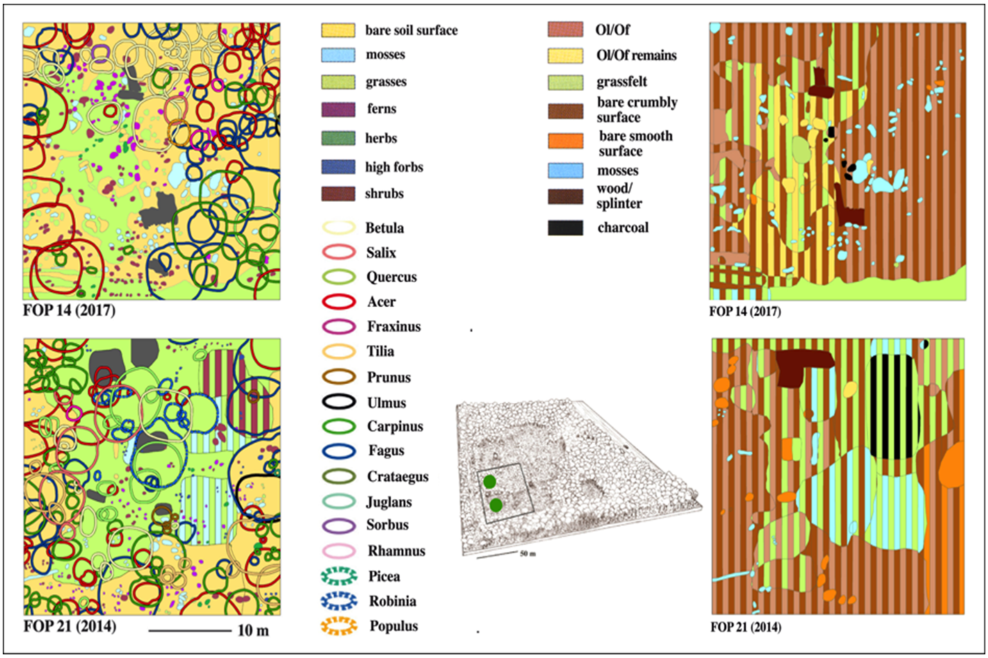

Fig. 9. Vegetation and soil cover maps of the early stages of succession in summer 2017. They depict the heterogeneity/diversity in the plant cover as well as in the soil cover.

The soil map depicts the young colonisation in the centre and the forest heritage at the western southern and eastern rims. Mosses are concentrated on the centre and in the North. The wheat field still shows the charcoals on the surface mixed with grass felts.

The second group comprises the middle and late stages of successions (Figure 10).

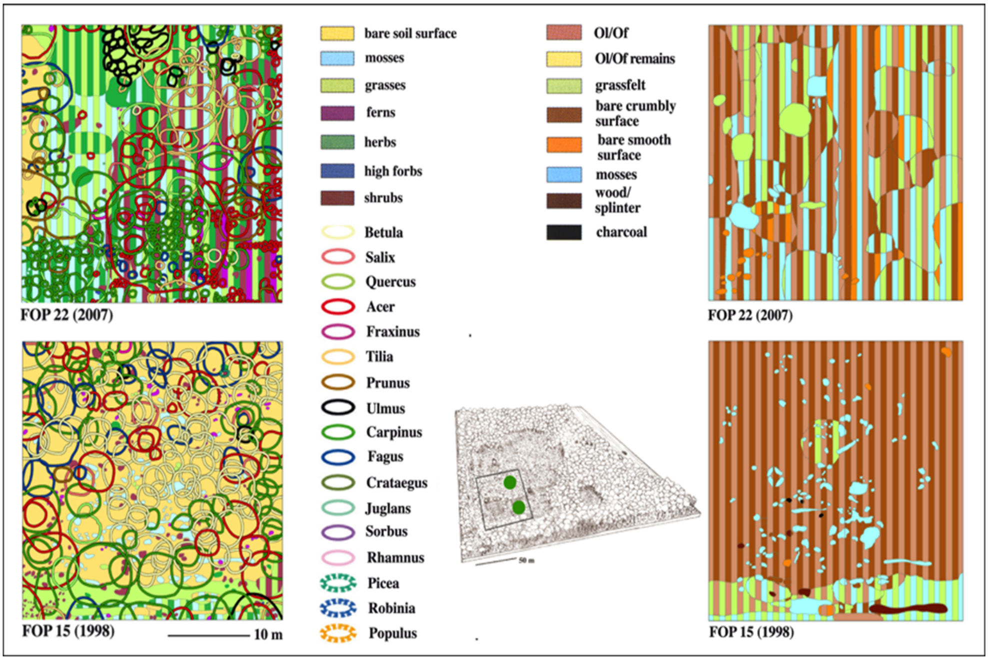

Fig. 10. Vegetation and soil cover of the middle and late stages of succession in summer 2017.

FOP 22. This plot is the first, which was firstly cleared completely in winter 1997/98 – with the exception of two *Quercus* and one *Acer* trees. After cultivation for two years, it was abandoned in 2000. In order to start with the rotation part of the project it was re-cleared in winter 2006/07. It was cultivated on several plots for two years and again abandoned in 2008. During the first period the plot was also used for pasture and a S-N fence divided it into two parts. Today, the plot shows the complicated mosaic of a middle state of forest succession. Two types of heritage are present by the old and high trees in the centre and the younger ones at the western rim. Trees colonised differently.

Ulmus acted in swarms by seedlings, *Acer, Tilia* and *Carpinus* by resprouting from stumps. *Salix* was a coloniser of the second tree generation arriving from seeds and in contrast to the other plots here it could build up groups. The plot is clearly divided by an old fence, which supported the tree colonising. The southern part shows the colonising by swarms of *Acer, Fagus* and *Carpinus* seedlings. Under the tree cover also *Rosa* could develop important stands in the shrub layer. *Hedera* is numerous in the southern part under the umbrella of large trees. A mixture of grasses, shrubs and herbs covers the soil surface. Mosses are important, which apparently it is the effect of a microclimate under the dense umbrella of trees and shrubs.

The middle stage of forest succession as also visible by the soil cover. Leaf covers and splinters dominate at the western rim and near the S-N fence. Mosses are generally present due to the microclimate under the crown cover. Grass felts characterise the former cultivation areas in the western part and the part of lower and scattered trees.

FOP 15. The plot depicts the longest series of successions – from 1999 on and it will serve as reference plot for forest development. The transect (see figure 8) shows the double type of regeneration as resprouting from the roots as well as by seedlings. As the crown cover got closed about five years ago, shrubs like *Rubus* were suppressed, as they were in the years before. Some open space in the crown cover allows some single tussocks – mostly of *Deschampsia*. The plot is dominated by trees, which could recover from the roots (*Carpinus, Acer, Tilia*). *Salix* is among the early colonisers by seedlings, but it remains as singular exemplar. The centre of the plot was colonised by *Betula* in one generation, where birch now dominates without younger exemplars. This took place within the border of the burned area. *Carpinus* and *Acer* always produced new seedlings, but only with minor success. Grasses and mosses dominated the forest track in the South.

The soil cover demonstrates the homogeneity of the dense tree cover. Ol/Of and splinters dominate. Grass felts are only present on a small open space in the centre. Mosses are scattered. They also cover old stems. Open bare surfaces are rare. As in FOP 14 also some places of charcoals are exposed, again the result of enchytraeid activity. The forest track in the South shows the mixture of grass felts, mosses and leaf layers as typical under the tree umbrella.

In conclusion the two figures (9 and 10) depict the evolution of heterogenity/diversity of elements and structures width a maximum in the middle stagers of succession and the change to homogeneity/ monotony in the late stages.

4.4. First conclusions on the evolution steps of soil and vegetation

This chapter concentrates on the interaction of vegetation and soil. The phenomena of fire and charcoals will be treated in a separate chapter.

4.4.1. The development of topsoil/ soil surfaces during twenty years of evolution.

When cleared, a forest soil changes rapidly its character (see figure 10). The disappearance of microclimate, the direct insolation and arrival of precipitation and mechanical destruction may lead to raw soil surfaces. They follow the stages of clay sealing / development of algae / bacteria film and a first installation of mosses. An arrival of seeds may lead to a first plant cover and in parallel to bioturbation.

A grass cover forms grass felts, which closes the surface densely and support an intensive crumbling by earthworms. The development of shrubs and trees leads to leaf layers, which indicates the forest environment. Depending on the intensity of alteration it could be an Ol/Of system or in special cases also the Ol/Of/Oh-formation.

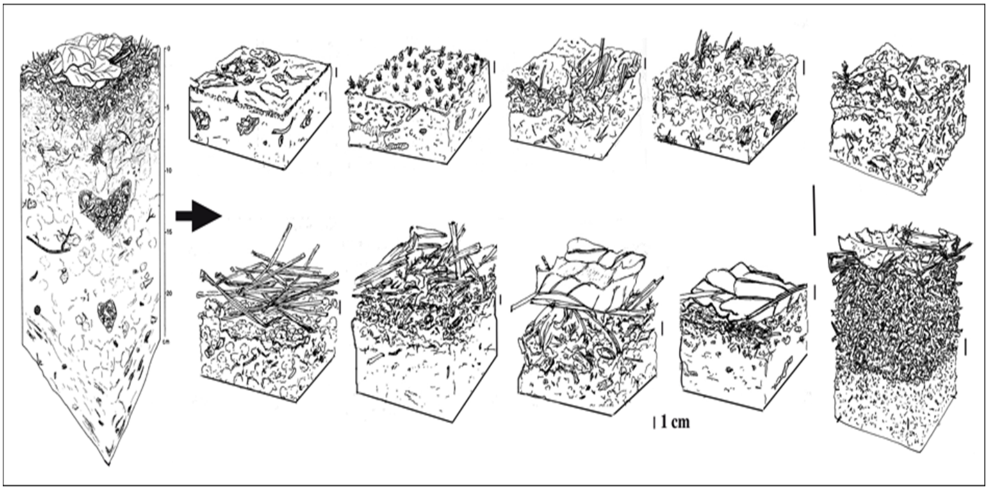

Fig. 11. The regeneration of topsoil/ soil surfaces from the original forest on after disturbance of clearing. It comprises the early stages of sealing and settling by mosses and grasses with felt development and the cover by leaf layers as indicators for forest (after Schulz et al. 2014, modified)

4.4.2. The coevolution of vegetation and soil - in the system of repeated disturbance (see figure 12)

The general trait is the evolution of a double mosaic (Schulz et al. 2014). The first one starts after the clearing with a rapid deterioration and/erosion of the former leaf layers (Ol-Of) forming bare surfaces sealed with clay or algae/bacteria films (1). It is a process of days. A second step is the formation of grass cover, either as clones (cf. *Holcus*) or tussocks (cf. *Brachypodium, Deschampsia*) and also some high forbs like *Epilobium* or *Eupatorium*. This mosaic is accompanied by grass felts, moss covers or crumbly surfaces (2). The burning of the plot after about 8 months and the subsequent cultivation destroy a greater part of the first mosaic but initiate a second one. It comprises the development of a grass- and herb-cover, the sprouting of high forbs and first shrubs like *Rubus*. The burned field remains covered with charcoal and free of vegetation for a long time.

Already in the second year the resprouting of some trees from their stubs creates a mosaic of grass-and herb-plains and some islands of leaf cover. Thus, there is a mixture of grass felts, moss cover, bare crumbly surfaces and first leaf layers (4-7). This succession will continue the following years with a development of dense shrub-grass covers (*Rubus-Deschcampsia*), the growing up of the resprouting trees and the installation of pioneers from seedlings (*Salix caprae, Fraxinus, Acer*). *Betula*, however, needs an old tree exposed to the open plots before a mass of seedlings may survive in the plots. It finally gives a second mosaic developing into a high and dense coppice within 15 years (8-11).

4.4.3. The ruderalisation and its consequences

From a certain time and openness of the test site, the high forb unit became stable about six years after the first clearing. In contrast to ordinary clearing floras, *Cirsium arvense* formed monotonous stands on several plots and dominated over years. Figure 12 describes this phenomenon for FOP 16. The plot was cleared in winter 2002/03 and repeatedly burned 2003, 2004, and 2005, each time on a different surface.

The maps for 2003 depict the predominance of grasses and high forbs. Shrubs – mostly *Rubus* – were scattered. The *Rubus-Deschampsia* unit remained close to the western margin. Soil surfaces were characterised by grass felts, mosses, splinters and bare crumbly surfaces indicate the intense activity of earthworms.

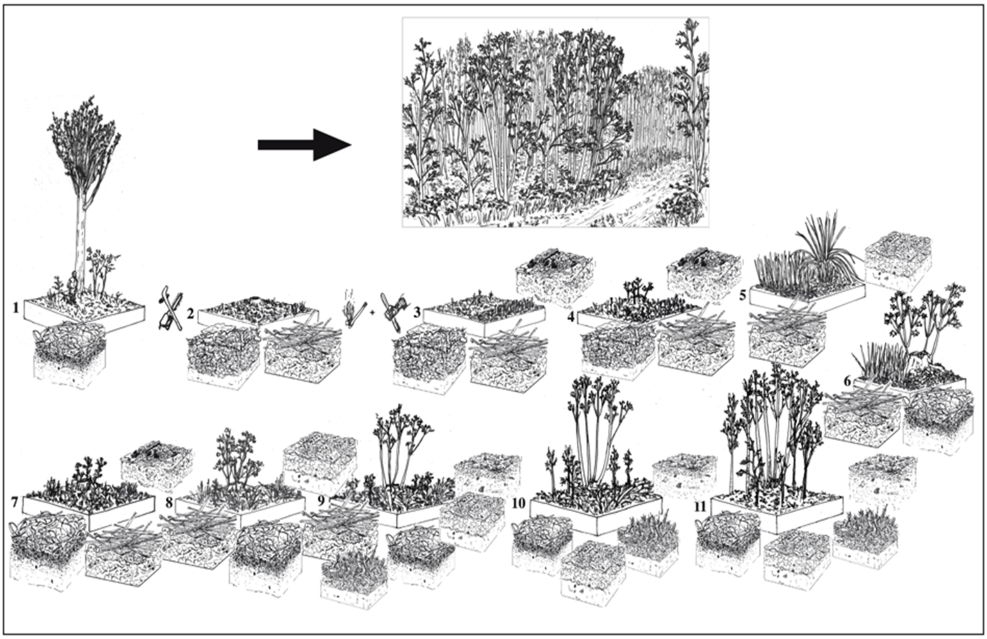

Fig. 12. On the way to coppice. Combined diagrams of vegetation stages and soil surface types for the regeneration after clearing to coppice development. It also shows the function of grass domes for intense earthworm activity caused by the constant microclimate beneath the tussocks (5).

Three years later the situation remained comparable. Grasses and high forbs dominated, the *Rubus-Deschampsia* unit remains in the western/north-western part. The soil surfaces are again characterised by grass felts splinters bare crumbly surfaces, which are supported by the microclimate of the dense high forb stands (*Cirsium),* and already leaf layers. Trees developed from the resprouting at the western margin.

This situation – hindering the installation of tree seedlings – lasted to 2008, when pioneer trees such *as Salix caprae* could well evolve.

Finally, it could modify the general picture of succession given in figure 12.

The “Ruderal Way of succession” shows the same scheme of development for the first stages (1-3, see figure 11). After the end of cultivation, the high forbs already did develop as strong that they could form dense thickets with a humid and stable microclimate. They also had a dense under storey of grasses, mosses and herbs - mainly *Glechoma hederacea*. *Rubus* was slowed down in colonising these areas and single seedlings of *Acer* or *Fraxinus* were asphyxiated.

Resprouting trees from stumps developed (Figure 13, 4 to 6), as it was typical for the other fields, but the implantation of all other trees was impeded – at least four or five years long. Only some *Fraxinus excelsior* hordes could establish themselves because they followed the same strategy in building up some dense stands as the high forbs and enabled a humid microclimate too.

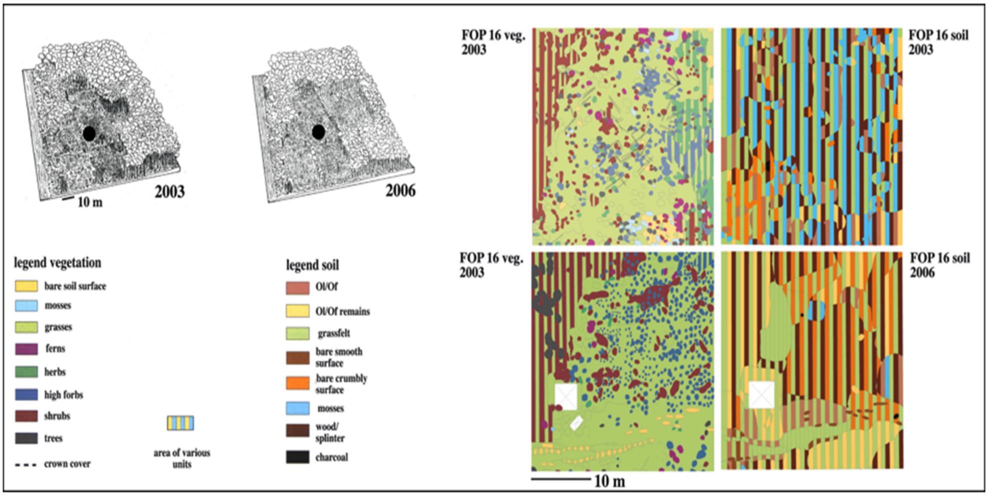

Fig. 13. The ruderal development. The figure shows the general state of the Forchtenberg test site in 2003 and 2006 and the evolution of the plot FOP16. The intermediate state of high forbs – especially *Cirsium* – got persistent for several years and impeded the establishment of seedlings.

The slow development of *Rubus* groups provided chances for some seedlings (*Acer pseudoplatanus, Salix caprae, Fraxinus excelsior* or *Prunus avium*). The following stage (7) was characterized by a rapid development of baskets from the resprouting tress and of some young trees, which managed to overtop the thickets. Later on, it caused a mixture of high reaching baskets and some isolated bushes/trees over the still remaining thickets, in which *Rubus* could reach up to three metres height. Their understory remained the same: some grasses, mosses, and mostly *Glechoma, Urtica dioica* and *Sambucus racemosa* became numerous, indicating an elevated nutrition reservoir.

It also incorporated elements of the *Aegopodium-Urtica* units (*Aegopodium podagraria, Lamium maculatum, Urtica dioica)* or those of forest margins such as *Alliaria petiolata* or *Glechoma hederacea*. Further on the *Onopordon* thrifts may have contributed *Cirsium arvense, C. vulgaris* and again *Urtica dioica*. Finally, these ruderal thickets might have evolved out of the classical clearing and forest margin floras and getting autonomous out of the rapid evolution of *Cirsium arvense* into long-time persistent *Cirsium - Rubus-* thickets. It was mentioned as being characteristic for areas with better soil conditions – in his case loamy soils [Dierschke 1988, Deil frdl comm.), but it was also stressed for the affinities of *Cirsium*-communities to alluvial environments. It could also be explained by the microclimate in the thistle stands. These phenomena are different to the initial clearing floras (see Ewald et al. 2018) and must be considered as a second ruderalisation.

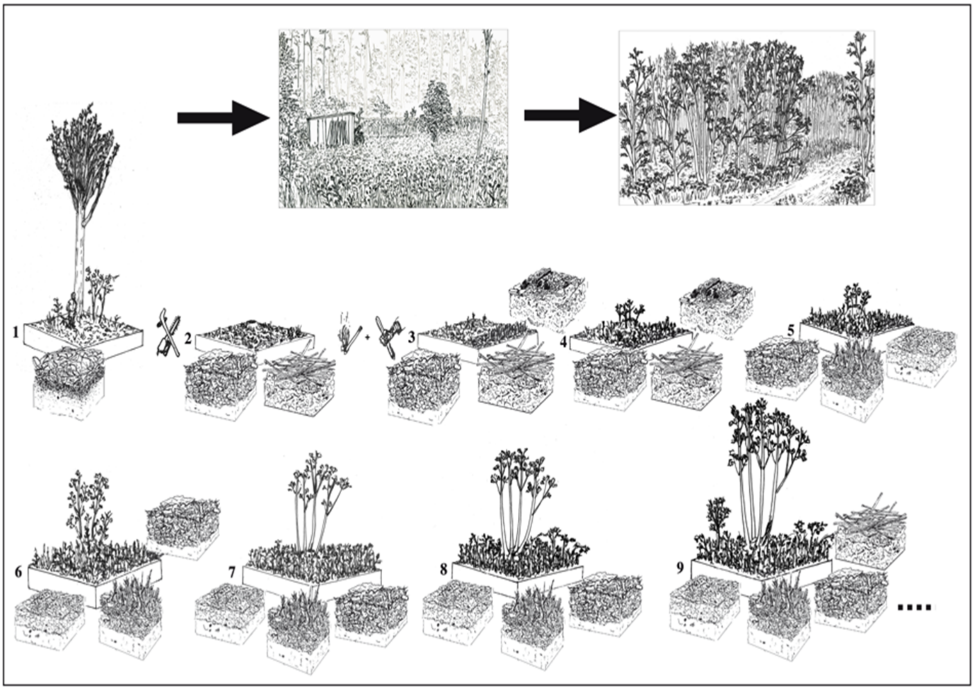

Fig. 14. The regeneration of topsoil/ soil surfaces from the original forest on after disturbance of clearing. The ruderal development of persistent high forbs (6-8) impeded the establishment of seedlings for several years. However, resprouting from stumps continued (after Schulz et al. 2014, modified).

4.4.3.1. Comparable features of ruderalisation. In the forests nearby, several areas were thrown down by storms in the year 2000. They have a comparable size – about half the test site, and, thus, they may serve for comparison to the features on the test site. Also, the original forests were comparable to the Forchtenberg-Büschelhof one - with the exception of one *Picea* areal. After the storms, these plots were all cleared of fallen stem. Afterwards they were designed for succession to an acceptable (for forest exploitation) tree composition. In case of doubts they were actively planted. Normally one counts in this area on a development to a forest within 10 years. However, some of these clearings were designed to a later afforestation or simply were forgotten. They all showed a development of dense thickets consisting of *Rubus fruticosus, Galium odoratum, Cirsium arvense,* but also *C. vulgare, Stachys silvatica* and grasses like *Deschampsia ceaspitosa, Dactylis glomerata* and *Brachpodium sylvaticum. Urtica dioica* was regularly present. Only a few bushes like *Sambucus racemosa* or *Salix caprea* could establish them and survive. However, near the margins of the forests several *Fraxinus excelsia* hords-and-thickets could grow up to about four metres height. Resprouting of trees was not a common phenomenon with the exception of some *Acer pseudoplatanus*-exemplars. *Betula* is present but it does not show important stands. Areas situated in depression have a notable amount of ferns (*Dryopteris filis-mas*). *Digitalis purpurea* was numerous on the plot of a former *Picea* plantations. Some rows of *Quercus petraea* and *Abies alba* were planted on one area in 2004. However, they were overtopped by the *Rubus* thickets and just only survived afterwards. Interestingly, also some thickets of *Cirsium arvense* evolved in the centre of some of these clearing areas, which reminded of the Forchtenberg site.

These vegetation units are rarely discussed in literature. However, the rare information in literature may also come from the fact, that these evolutions of persisting clearing/ruderal floras normally provoke intensive counter-measurements from the forester's site. There is a report in the "Natural Forest Reserves" in the Hunsrück-Mountains and Palatinian Forest / western Germany (41), which mentions these thrifts on storm affected areas with " a certain phlegm for successive changes". The authors also reported that these vegetation types mostly developed on plots, which were cleared from the wood thrown down by the storms. It got evident [42], that on clearing plots the soil surface is as much opened and disturbed by removing wood, that elements from the seed bank will be favoured among them *Rubus* sp., or *Juncus* sp. There also is enough open space for elements with favourable seed dispersal such as *Epilobium* or *Betula*. They ranged wild fires into the same category. Chances of an exploitation of secondary successions after a severe wild fire of a *Pinus-Betula* forest in north-eastern Germany were discussed in a different way (Stähr 2012). Areas cleared from the burned wood showed after eight years a succession of bushes and trees near to an exploitable forest. On plots with decaying stems, however, some pioneer trees established with well-developed crowns above a dense ground flora, which impeded a further rejuvenation of trees. Anyhow, these ruderal phenomena are not uncommon, but normally they are not acceptable for the foresters, because they spoil the production time of trees. Their answer in most cases is a clearing of the high forbs. Thus, the development on the test sites gives a good model of succession stages, which in normal forestry is not tolerated and counteracted. It is certainly one reason why these phenomena are rarely discussed in literature.

4.5. Intrusions of exotic elements during regeneration

The number of "exotic" tree species is very low. Only *Quercus rubra* settled in numerous exemplars. *Robinia pseudacacia* was successful on three different plots. Conifers are very few. *Pinus silvestris, Larix decidua* or *Picea alba* arrived late in the succession plots, although they are present at the edges of the test site (see figure 1). Thus, even ruderalised by high forbs, the test site remained in a forest dynamic. As tillage was restricted to a short period only, the high forbs – especially *Cirsium arvense* – were able to colonise rapidly the respective plots due to their dual strategy combining a high seed production with a vegetative expansion by rhizomes*. Solidago canadensis* was only successful on one plot (7), however, it is restricted by the *Rubus* bushes.

5. THE IMPACT OF FIRE

Fire is a traditional tool for landscape management (GFMC et al. 2010, Goldammer and Page 2000, Goldammer et al. 1997). Different types of fire and their consequences for the soil cover are analysed both for the slash-and-burn experiment Forchtenberg as well as for the forest fires site in NW Romania.

5.1. The burned topsoil/soil surfaces at the Forchtenberg test site

As mentioned above two different types of burning or temperature impact existed on the experiment plots. Pulling of the inflamed roll of branches caused a mosaic-like impact. It ranged from slight heating of the upper centimetres of plant cover and soil with only light damaged to a complete destruction of organic matter and sintering of the loess material. Temperature measurement during operation showed values between 70^{o} and 200^{0}C for the surface near material (Ehrmann et al. 2009, Rösch et al. 2011). However, refraction measurements pointed to a heating up to 900^{o}C (49). It may be explained by the attraction of cold air from the sides, that these temperatures could not affect the soil surface itself (see figure 16). The "alimentation" fires – to produce enough charcoals for the burning roll - were active for more than five hours and affected the loess material more intensively (see figure 15). Estimations from the degree of cementation and from the colour of the burned loess material range from 400^{o} to 900^{o}C (Hartkopf-

Fröder et al. 2012). They are based on own burning experiment of the forest soil material.

5.1.1. Effects of high temperature burning in the Forchtenberg experiment

In 2011 – three months after the burning – some structure samples for micromorphology were taken on the alimentation fireplace in FOP3 (see Figure 14). Sample “a” was intensively heated and transformed into a brick, sample “b” got a less intensive heating and showed a minor consolidation. Sample “c” came from the alimentation fire on FOP 11 in 2012. It also was completely cemented, however, with a less consolidated structure. All samples were analysed for their structure under the stereomicroscope, also thin sections were made. Sample “a” depicts a dense package of quartzes in the upper part and organic matter completely disappeared. A web of iron oxides developed and quartzes are cemented. In 3.5 cm depths some organic matter remained between the quartzes, perhaps due to an isolation effect of the upper “brick” section.

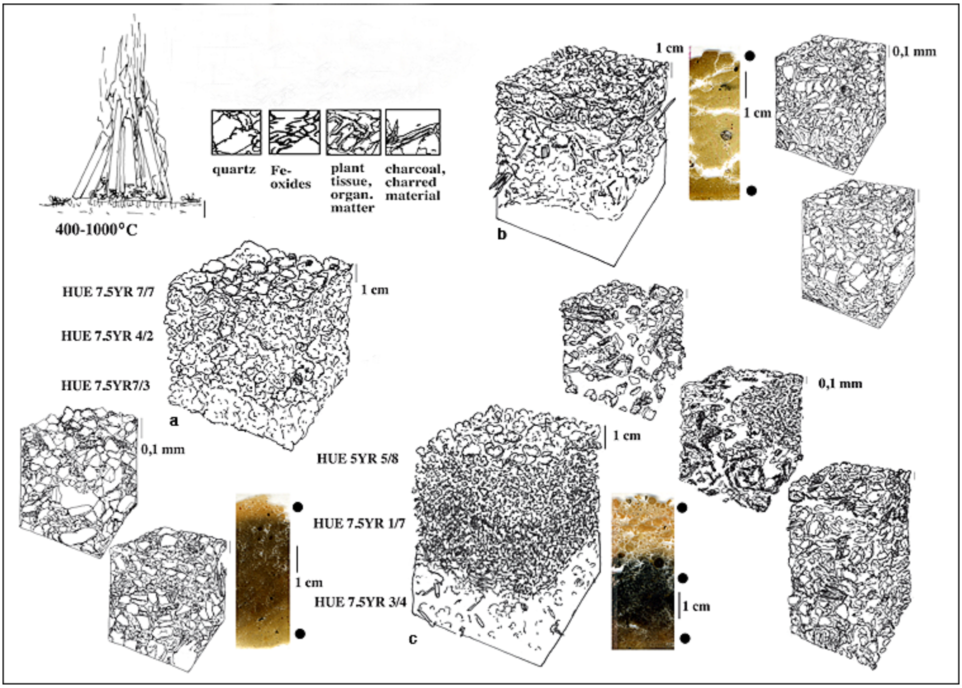

Fig. 15. High temperature burning. A combination of structure soil samples and thin sections. The figure shows the dissection and / or cementation of the quartzes and the condensation zone of soot above the original soil material (after Schulz et al. 2014 modified).

Sample “b” is intensively crumbled with a dense quartz package and an iron oxide web. Some charcoal pieces are incorporated. However, the material was not transformed into brick. The lower part (3.5 cm) is condensed too, but still some plant tissues are preserved. Both samples have a sharp border between the burned upper part and the original loess beneath. Sample “c” shows similar features, but the dark middle part may represent the condensation front of volatile C-molecules during fire (Hetsch 1980, Bührle et al. 2011).

These observations confirm former conclusions (Bauer 1968, Varela et al. 2010) that temperatures higher than 400°C are necessary to destroy soil aggregates and lead to condensation and, thus, to augment the water repellence. There is a condensation level of soot, which did protect the organic material in the lower parts of the soil. The evolution of this intensively burned material may be considered as “neoformation”, because all the organic material and so the seed bank too was burned and the siliceous material also got a new structure as a parent material. The development could be followed on several alimentation fireplaces. It started from a pulverised or fragmented material to a first sealing of clayey of silty material. This took several months. A similar time was necessary for a slight settlement by algae of fungi. Mosses only appeared after more than ten months. After these long phases of transformation, topsoil will continue in those directions already explained for the non-burned soil surfaces (figure 10).

5.1.2. Effects of low temperature fire. The burned field in the Forchtenberg experiment

Fire impact on the burned field was very different depending how long the burning roll was present at the respective places. Only moderate damages occurred at the margins of the field, and some mosses still remained at the surface. The loess material is not consolidated and incorporates many pieces of charred material, which is also the case for the sample at four centimetres depths. The sample from half a meter into the field shows a loose mixture of crumbs, root-remains, and an ash - charcoal cover. The surface has open fissures with some charred material. At 4 cm-depths root-structures are still visible. The material from the centre of the burned field has a loosely crumbled structure is loosely and shows a bare surface with some charcoals. Roots still remain. The package of the loess is not as dense and it incorporates a lot of charred material in the upper millimetres. Some plant tissues are present in about 3 cm-depths.

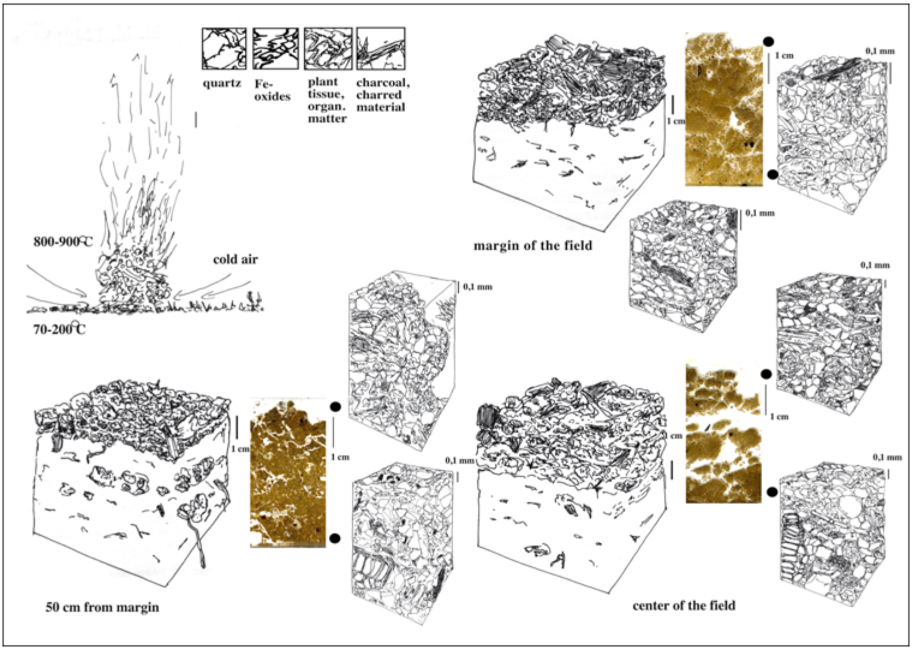

Fig. 16. Low temperature burning. A combination of structure samples and thin sections. The samples show the charcoal layers on the field, the clear divide between the loose overlay and the compact soil material and the preserved-survived organic material after the passage of the fire roll (after Schulz et al. 2014, modified).

5.2. The evolution of topsoil/soil surfaces and the fate of the charcoals, seen from the Forchtenberg experiment

The small-scale mosaic of the burned fields induced a variable evolution. During the first years of the experiment the surface remained bare unless some grasses or mosses could directly recover. Normally, it took several months before single grasses of herbs could establish. The question of seed bank interaction, however, remains open. The next stages were similar to those schemes already mentioned above. Grass felts changed to leaf overlays. Grasses like *Brachypodium* or high forbs like *Cirsium* established themselves very early and persisted on the areas of ruderalisation, despite some weeding on the cultivated plots. Charcoals got weathered by swelling and shrinking or by frost action; for the most, however, by the uptake of earthworms. They displaced them vertically to more than 20 centimetres depths in about 11 years (see figure 17). However, there were also accumulation of charcoals near and on the surface, which may persist more than ten years. In these cases, the soil structure completely changed. The crumbs made by earthworms were replaced by smaller and densely packed aggregates, as it was detected by micromorphology. As already explained above, the main goal of micromorphology was structure. Thus, it was not possible to destroy the soil sample in order to isolate the soil animals for determination. However, the main groups were easy to observe and to detect in the original samples as well as by their droppings in the thin sections. Enchytraeids, mites, and collembols colonised regularly these accumulations. In all, it represented a dense mixture of some greater charcoals, grey to black aggregates of Enchytraeid and mite droppings as well as small and deeply weathered and densely packed charcoal pieces. Often, they showed sharp limits to the loess transformed by earthworms. The surfaces of these accumulations were either bare and fragmented or covered by mosses or leaf overlays.

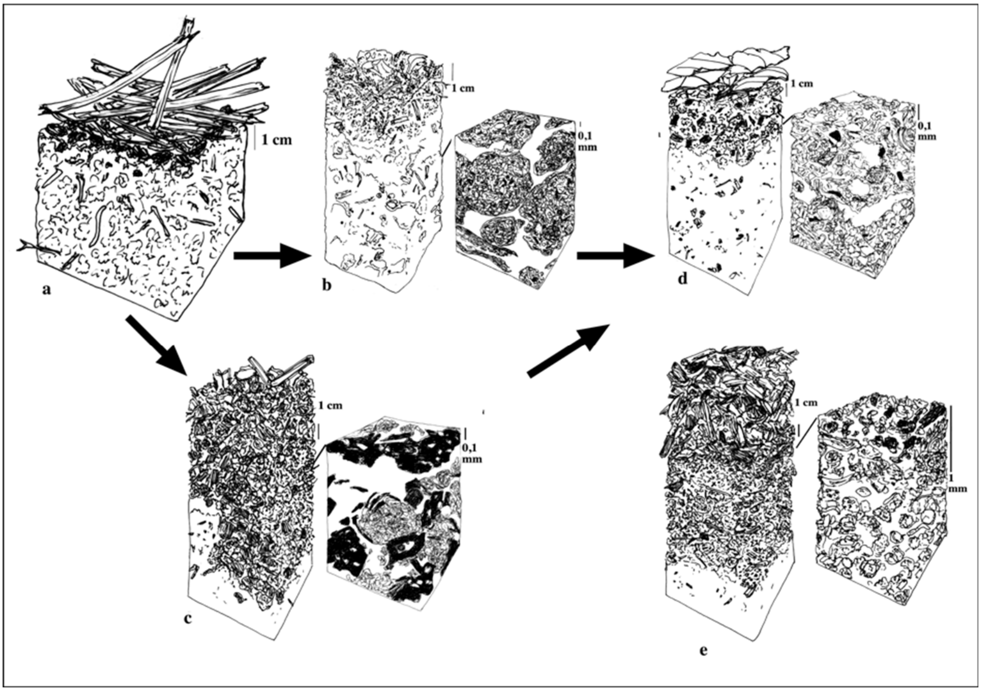

Fig. 17. The taphonomy of charcoals. After the coverage by grass felts (a) the development of charcoals depends on the influence of soil animals. Earthworms – visible by their droppings – will displace them vertically (b). Enchytraeids/mites/ collemboles will concentrate them near the surface and weather them in situ (c). At places of recultivation – within the rotation system – the loose charcoals layer by enchytraeids (d) is distinct from the soil beneath influenced by earthworms. Finally, it is a model or surrogate for an Ap. Ants (e) avoid charcoals for their subterranean constructions, but use them as material for their subaerial buildings.

The difference of weathering and bioturbation of soil/charcoal material by earthworms on the one side and by enchytraeids, mites and collembols on the other side was already described by (Carcaillet and Talon 1995, Topoliantz et al. 2000, 2006) from the temperate regions as well as from the tropics. Here it was characterised as the main weathering process leading to "terra preta do indio" (Glaser 2007). The causes for the parallel presence of these different taphonomic processes of charcoals remain as an open question. Might be, that there is a succession, in which at a given time the enchytraeids, mites and collembols take over sites formerly colonised by earthworms. On the test site, these accumulations were detected on pseudogleyic Luvisol, however, on a sandy loess material.

These factors may unite as favourable conditions for enchytraeids, collembols and mites. They are known as feeding on slightly rotten biomass in the lower part of leaf layers forming moder or raw humus as well as secondary feeders of earthworm droppings too. Their ph.-tolerance is higher than that of earthworms (ph values 4.6-5.7), accepting ph values of 3.2 in a beech forest of Solling/ Central Germany (Weigmann 1968, Zachariae 1994). Also, a higher pore volume is necessary as mites and collembols are not digging organisms. The structuration factor of these communities plays an important role (Blackford 2000), because enchytraeid-droppings are very stable. Finally, in terms of soil development it might be considered as a formation of moder on an exotic substratum.

There is also another implication (Clark 1988). The linear relation of depths in the soil profile and the age of charcoal seems to be only one model among others. It also could be that the transport of charcoals flitters from a burning site is not only a short time process as proposed before (Clark et al. 1989, Ohlson and Tryterud 2000). It also could be that the mixture of earthworm-weathered and enchytraeid-weathered could well influence the charcoal deposition in lakes or ponds after erosion/transportation in a parallel way. That should be considered for age estimations.

The third animal group affecting soil is ants. They regularly transform the topsoil material into a loose but stable kind of mineral/organic mull. It is a very typical structure actively formed by the ants in chewing and mixing the mineral and organic material and building a web out of it. It destroys all former structures and creates a monotonic new one (Frouz and Jilkova 2008). However, in the Forchtenberg test site ant-nests became numerous only in the last five years. One place allowed observation of the ants structure of soil material in direct contact to charcoals of a burned field. It became obvious, that ants use charcoals as building material for their subaerial constructions. However, they avoid them for the subterranean buildings.

5.2. Disturbance and regeneration at the Leghia wildfire site. Comparison with the Forchtenberg observations

At the Leghia- site we concentrate on transects, pedology and micromorphology.

5.2.1. Decay and recovery

Two processes are active simultaneously. This is the decay of the burned pine stands and the regeneration of vegetation and soil. Trees are falling down and start to decompose slowly and in the same time vegetation recovers.

The undershrub recovered remarkably and is characterised by some submediterranean elements like *Ligustrum* or *Cornus* shrubs. New seedlings belonged to deciduous forests and some dense stands of maple could develop.

The Leghia site depicts well that within four years the fate of the charcoals depends on the type of vegetation and of soil animals. Deciduous shrubs support the earthworm activity whereas the pine needles and splinters favour enchytraeids and mites. They produce small edged crumbs and millimetric droppings full of microcharcoals. Figures 19 and 20 will explain these processes. After the ground- and crown fire a new formation of $O_l/O_f/O_h$-layers took place and so, an accumulation of fuel again. It consisted of needles, cones of twigs and bark with a variable content of macrocharcoals. One can discriminate enchytraeids and horn mites by their droppings. However, those of earthworms are rare. Figure 18 represents the lower transect with the mixture of deciduous bushes (*Robinia, Cornus*) and the burned *Pinus*- stands with living and dead exemplars. Thin sections of a soil sample beneath a pine tree show the loose charcoal pieces in the upper part and the consumed and smaller ones in the different droppings. Thus, there is a tendency of moder- or O_{h-} building, which holds the coarse charcoals near the surface. One may also observe the development of different layers of loose and edged enchytraeid-crumbs with evenly distributed microcharcoals. These two features may be due to the contrasting seasonality of the site. Desiccation during summer may disintegrate the loose system of fine crumbs, only fixed by roots.

During the wet seasons the material may swell again. The repetition of this process will lead to a continuous grounding of charcoal. However, as visible by the double Oh-layers, slope erosion will also play a certain role. The transect up Figure 19 shows that a group of *Acer*-trees already induced a stronger differentiation in the soil structure (see figure 19).

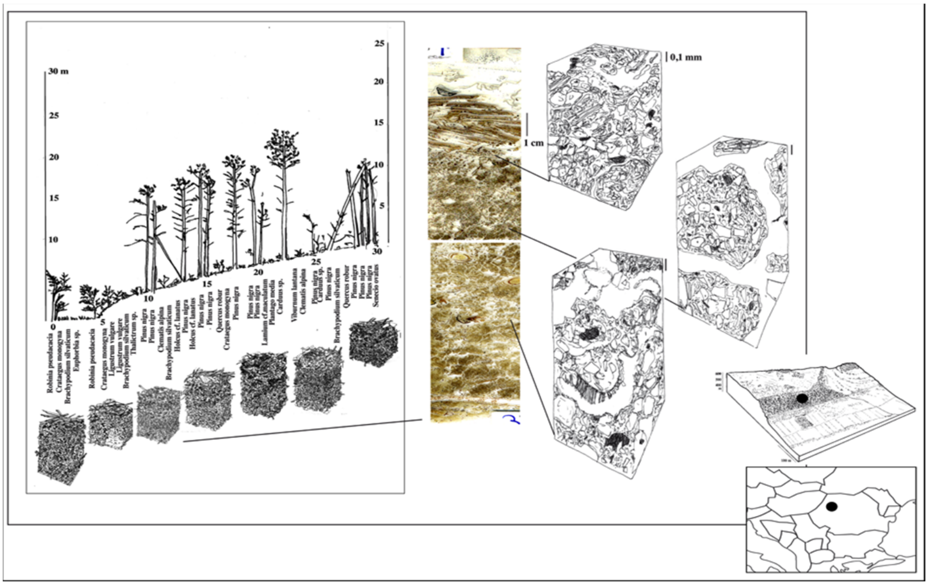

Fig. 18. Transect of vegetation and soil on the lower slope of the Leghia wild fire site (for location see figure 3). It is visible that only seedlings from deciduous trees recover. The moder-sample depicts the needle packages, the droppings of enchytraeids and the general presence of charcoals.

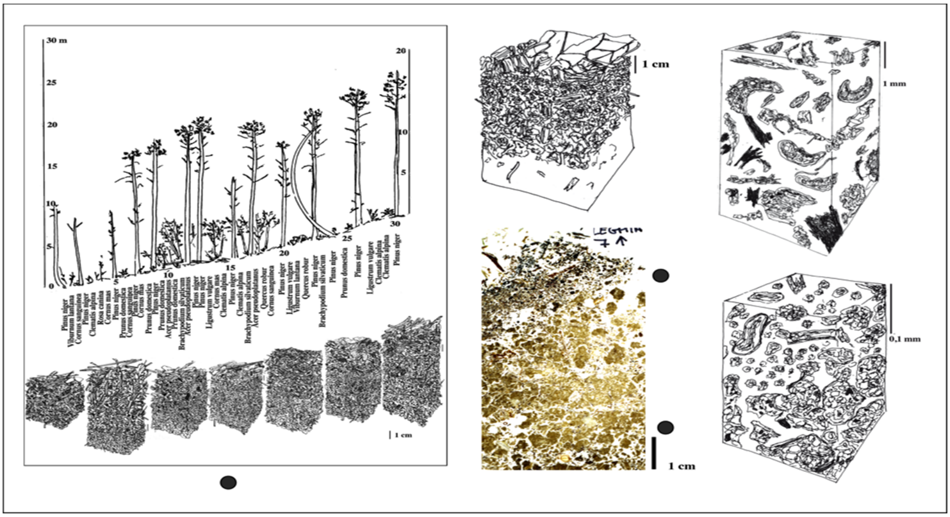

Fig. 19. Transect of vegetation and soil on the middle slope of the Leghia wild fire site (for location see figure 3). One moder sample beneath an *Acer-Fraxinus* group in the centre depicts the loose structure by Enchytraeid- and mite-droppings and needle- and leaf-remains in the upper part. Charcoal is generally present.

5.3. Fire in the open land

In the intensively exploited cultural landscape of Central Europe, non–intended fires are rarely to discriminate from fires originated by accidents or by exploitation. Three examples from Germany and from near the Leghia cuesta will describe these phenomena.

Fig. 20. The burning wheat-field at Seinsheim near Kitzingen, northern Bavaria. Note the enormous cloud of smoke and ashes as well as the structured field by clearly limited plots of unburned wheat in the ash field. Topsoil/soil surface diagrams depict the situation between the unburned stems (a) and on the burned field (b-d). The block e shows the situation at the margin field, where charcoal flitters lay between the loose crumbs.

5.3.1. The Seinsheim fire in summer 2013

In August 2013 one could observe near Seinsheim (Kitzingen region, N Bavaria) that a great wheat field (about 1 ha) took fire on a very hot afternoon. Flames did run rapidly over and reached about 8 m height. There were clouds of ash up to about 25 m. Astonishingly, it gave a mosaic of completely burned surfaces and stands of dried but not burned wheat with sharp borders to the burned areas (figure 21).

The soil surface was bare or covered / scattered with fusiform, millimetric and volatile coal particles. The soil was cracked and some charcoals particles were filled in these cracks down to 4 cm. As many of the wheat stems were also burned down to about three cm below the surface, it may explain that charcoal also occur in the upper soil from these phenomena. Anyway, the charred particles were small, very light in weight and easily blown by the wind.

5.3.2. Intended fire on open land. Burning of stubble fields and flaming of pastures

Flaming of pastures or burning of stubble fields is still common practice in large parts of the Carpathian basin. It serves to get rid of useless and dead organic material and to provoke the sprouting of fresh grass for pasture. The results of flaming could be observed and analysed on two sites near the forest fire site at Leghia, Transylvania (see above).

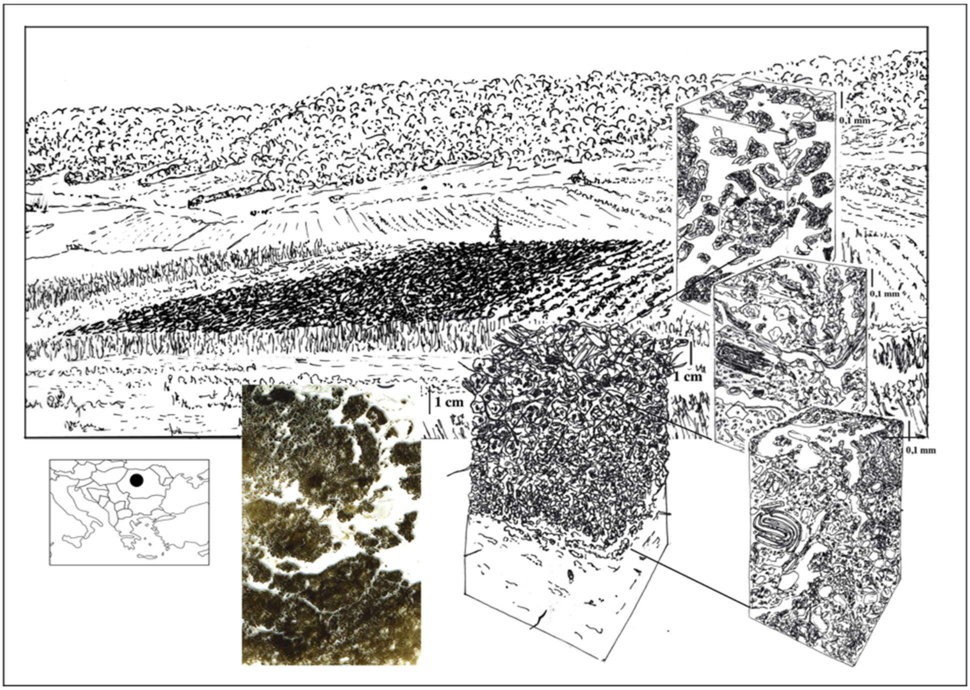

Fig. 21. The flamed wheat field near Gârbău, western Transylvania. It shows the small structures of the cultivated land, the flamed area after harvesting and the topsoil/soil surface with a regular presence of charred material in enchytraeid-crumbs and an A_p-horizon. The two block diagrams at the right show the situation after one year. The clayey soil was condensed after the summer months and showed almost no structure.

5.3.2.1 Flaming of stubble fields. A burned wheat field near Gârbău, about 10 km east of Leghia (figure 21) was sampled for soil structure and micromorphology in September 2014. The samples were consolidated afterwards and transformed into thin sections. The charred material was densely distributed within the enchytraeid crumbs and their droppings. Below four cm there was a sharp change to the consolidated material beneath, depicting a clear A_p-horizon. In contrast to fire use in forests the charred material comes from grasses. This coal is fusiform, millimetric and very volatile. The situation also illustrates clearly the effects of fire on soil (Certini 2005, Pomel and Salomon 1998). It leads to a disintegration of soil aggregates, a loss of fines in the upper millimetres, a destruction of organic matter or its mineralisation as well as a cracking and subsequent mulching of the upper centimetres.

5.3.2.2. Flaming of shrub and pasture. The second example was an extensively used pasture below the cuesta with the burned forest near Leghia (figure 23) and the soil surface beneath a *Cornus*- shrub. It shows the phenomena of a short flaming. Grasses are burned to their base but the charred material is only present in some runnels on the surface.

The topsoil and soil surfaces are bare and crumbled with some clay sealing. Charred material is evenly distributed in the upper centimetres mostly by enchytraeids, but apparently also by swelling and shrinking, provoking a kind of “micro-mulching”. The crumbs are loosely fixed by the grass roots. The surface below the shrub shows a mixture partly burned material, grass coal in a fine layer or a thick layer of ash, which will be diluted/ destroyed very rapidly. Runnels of earthworms contain many of the microcharcoals.

A meadow, which was burned half a year ago and was freshly ploughed only show some remnants of the grass coals in some cracks and between the ploughed areas.

These two sites may well give an idea of what was present in the western part of Central Europe half a century ago, before the general interdiction of fire use in the open landscape.

Moreover, they explain the general differences of charcoals from wood and from grasses (see above). The latter are much smaller, sometimes needle-like or fusiform. They also expose the siliceous incrusting of the epidermis and the stomata with their characteristic sickle-like cells. Grasscoal is produced in great quantities, but it is highly volatile and fragile. It also is associated to phytolithes (Neumann al. 2000, Woller et al. 2009), small siliceous particles from grass cells and incrustings (see figure 34). However, in reconstructing former landscapes the term “charcoals” is mostly associated to burned wood. It is obvious that at least one should estimate the percentages of grass- and wood coal for the reconstruction of former fire and landscape dynamics (Feurdean 2012, Marlon et al. 2016).

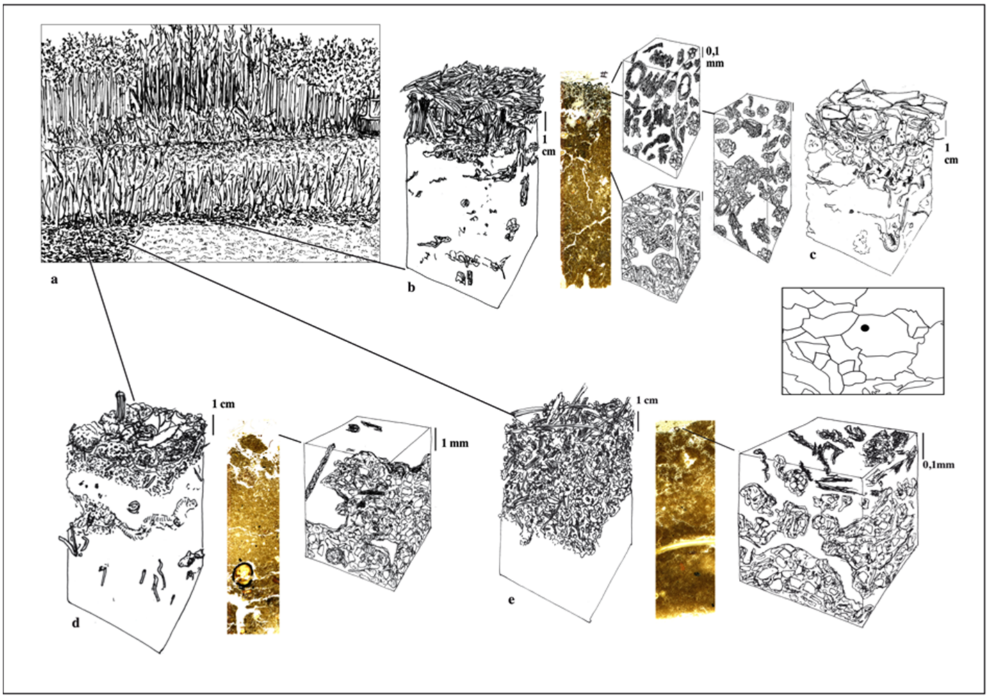

Fig. 22. Autumn flaming (2015) of shrub and meadow in front of the Leghia escarpment (a). It shows the burned underground of bushes with a thin layer of grass coals and a thick ash layer representing a very fresh fire (b). In the next spring some of the coals flitters are already displaced in the earthworm pipes (c). An almost unburned part of the grasses below the bushes (d) shows very few grass coals. The flamed meadow (e) is characterised by a thick layer of half burned grass stems and coal flitters.

Summarising, the Leghia site provides information on the nature of "wild" fire, on the nature of regeneration in a conifer forest leading to moder formation caused by enchytraeids, horn mites and collembols. Moreover, it depicts the general difference between charcoal and grasscoal. Thus, for reconstructions of palaeoenvironments both types of charred material should be considered.

5.4. Risk assessment

It is quite common sense, that deciduous forests in temperate regions are not inflammable. Moreover, that scheme is a base to interpret charcoals findings, whether in soil or in sediments, as witnesses of human activity. However, during the last 15 years - in August 2003-2006-2009-2012 we had long dry periods. Summer 2015 stands as the driest since 1761 (KLIWA 2006, Badek et al. 2004, Ehrmann et al. 2009, Becker et al. 2015, Horn 1980). This resulted into a remarkable leaf shed in August and an almost pulverised topsoil. But in August 2015 and 2018 the situation changed completely (sse also Meining 2018). Topsoil was pulverised too with no humidity in the upper 10 cm but the trees had a water stress, which was as severe that twigs lost turgor and leaves dried on them. Moreover, they curved up at the margins. After falling down, they formed a fluffy leaf layer in contrast to the other dry periods, where they laid flat on the soil surface in Forchtenberg. Figure 23 demonstrates the ordinary topsoils beneath conifers and deciduous trees. However, after months of drought the topsoil got pulverised and leaved fall in August 2015 and 2018. Contrary to other years, branches and twigs lost their turgor and leaves dried on the trees. They got crumbled and formed a very fluffy OL. Finally, any ignition could cause a rapid ground fire and leak to the twigs and crowns of the conifers nearby. This situation held about one month.

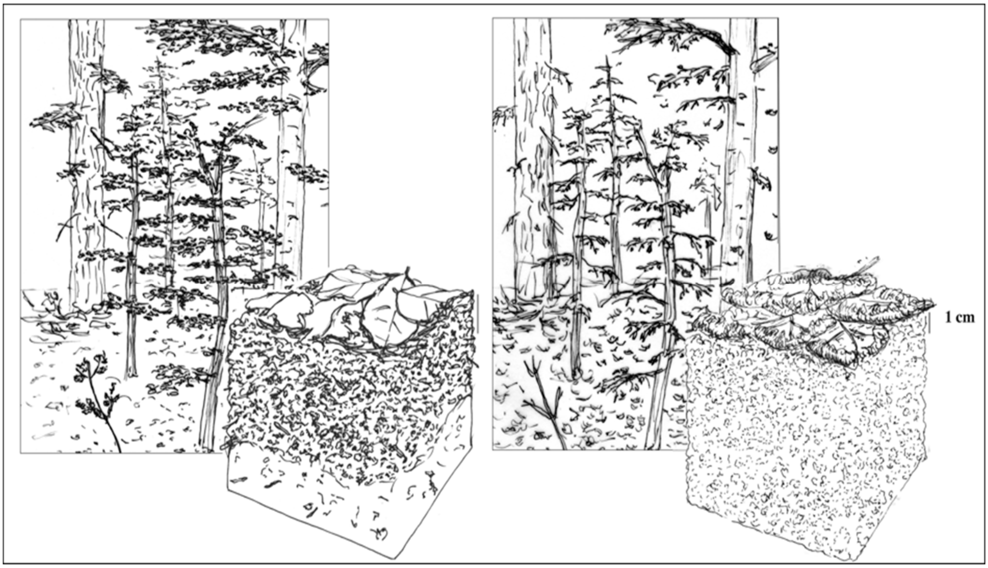

Fig. 23. Risk assessment in deciduous forests. The situation in August 2003, 2006, 2009, 2012 (left) with a premature leaf shed lying flat on the soil surface and in 2015, 2018 (right) with a fluffy layer of crumbled dry leaves.

This was observed in several forests in the state of Baden-Württemberg. With the first tiny rainfall and dews formation this risk-situation was over, as leaves became flat on the soil surface again.

As a fire needs fuel, a suitable environment and ignition energy, the risk of a ground fire was present for some weeks. Moreover, as several conifer stands are present in many forests the ground fire could have rushed to them and leak up to become a crown fire too. Thus, we have to abandon the old idea of inflammable deciduous forest especially in a changing climate. And fire management is to be incorporated in the future planning of deciduous forests.

In parallel, the series of droughts accumulated the water stress – not only for the flat routers but also for the isolated old trees or for facade-trees exposed to wind and dry air. This evidenced that the big water cycle was affected by the lack of sufficient recharge of groundwater. So, they got weak and susceptible for insect attacks, as it is visible for conifers. In addition, the growing epidemic of *Hymenoscyphus pseudoalbidus*, a fungus invader from East Asia, will probably damage or kill most of the *ash* trees or their seedlings (Offenburger 2017). This will augment the chances for storm casts in the next years and, thus, islands of new successions (cf. Fischer 1990).

6. CONCLUSION

The analysis of the pathways of secondary succession of vegetation and soil after forest fire as well as on slash-and-burn experiment sites yielded a series of results:

- A very rapid regeneration of topsoil / soil surfaces in developing pellicular surface structures ranging from clay sealing to bacterial / algae films stabilising the surfaces. These stages might be regarded as primary and obligatory succession (Gatter 1996), particularly on the long-time burning plots, where temperatures of about 1000^{0}C were reached.
- A subsequent evolution of vegetation and soil in parallel as secondary succession lines alimented either by seed banks or from the surrounding forest.

The impact of soil animals is crucial for the succession lines. Different types of charcoal preservation well illustrate it. Earthworms shape crumb structure and disperse charcoals. Enchytraeids, collembols and mites build a small pellet-structure and maintain an in-situ-weathering with the creation of charcoal horizons near the surface. Ants, however, produce a homogenous soil structure of small pellets but avoid charcoals for their subterranean constructions. As mentioned above there is a strong interdependence of vegetation, soil animals and soil development.

The two forest sites well explain the capacity of fire / fire use in shaping or maintaining a variety of structure from the landscape scale to that of soil micromorphology. This is the opposite of abandonment, which provokes succession lines for permanent shrub or forests.

The sites of open land fire demonstrated the different nature of grass coal being small, fusiform and highly volatile. They also showed the mosaic structure of the burned surfaces, where plants could remain more or less untouched in the middle of burning. This again underlines the structure creating dynamic of fire. Accumulation of grass coal was low with the exception of the flamed wheat field, where flaming apparently is a regular phenomenon.

Finally, all the sites demonstrated the possibility of fire to shape landscapes or parts of them either if the fire is used by man or it is not intended.

However, the general interdiction of fire use in the open landscape and in forests may lead to the accumulation of fuel and to a higher fire risk. Moreover, the loss of experience of a right fire use may also create some risks. Several initiatives for landscape management already showed the usefulness of fire management in a sense of prescribed burning (Schreiber 1981). There is a general conflict in nature conservation whether to follow strictly the present interdiction or to propose and reintroduce a meaningful use of fire, especially in nature conservation. However, it also became clear from the Leghia site that the introduction of monotonous conifer stands will create fire prone landscapes, especially in regions of contrasted climates, not to tell about a future climate change.

On the other side, the observations during the Forchtenberg work evidenced a general risk of fire for deciduous forests in very hot and dry summers, which may increase with a changing climate too.

ACKNOWLEDGEMENTS

Fieldwork for the Forchtenberg- and Leghia projects was supported by Stoll-Vita- and Würth-Stiftungen, by Deutsche Forschungsgemeinschaft and by the Pedological Research Institute Cluj-Napoca. We are indebted to them all.

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