Chapter

Soil Degradation Processes Linked to Long-Term Forest-Type Damage

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Abstract

Forest degradation impairs ability of the whole landscape adaptation to environmental change. The impacts of forest degradation on landscape are caused by a self-organization decline. At the present time, the self-organization decline was largely due to nitrogen deposition and deforestation which exacerbated impacts of climate change. Nevertheless, forest degradation processes are either reversible or irreversible. Irreversible forest degradation begins with soil damage. In this paper, we present processes of forest soil degradation in relation to vulnerability of regulation adaptability on global environmental change. The regulatory forest capabilities were indicated through soil organic matter sequestration dynamics. We devided the degradation processes into quantitative and qualitative damages of physical or chemical soil properties. Quantitative soil degradation includes irreversible loss of an earth's body after claim, erosion or desertification, while qualitative degradation consists of predominantly reversible consequences after soil disintegration, leaching, acidification, salinization and intoxication. As a result of deforestation, the forest soil vulnerability is spreading through quantitative degradation replacing hitherto predominantly qualitative changes under continuous vegetation cover. Increasing needs to natural resources using and accompanying waste pollution destroy soil self-organization through biodiversity loss, simplification in functional links among living forms and substance losses from ecosystem. We concluded that subsequent irreversible changes in ecosystem self-organization cause a change of biome potential natural vegetation and the land usability decrease.

Keywords: global environmental change, pollution, nitrogen deposition, deforestation, soil self-organization

1. Introduction

Human activity induces degradation of many ecosystems, of which the forest degradation results in far-reaching alterations in nutrient cycles in other related types of the environment. The forest degradation, including impacts on ecosystem functions, is intensified by terrestrial environmental change. Forests are most affected by felling and critical loads of pollution. Both processes may be characterized by negative impacts on soil which subsequently causes a decline in the forest natural ability to regenerate [1]. The damage of forest soils signifies that the development of potential natural vegetation is endangered. Damaged forest soils do not allow restoration of original plant community due to disturbed mitigation of environmental fluctuations. Soil capability to mitigate environmental fluctuations resides in uninterrupted cycles of organic matter and continuous fertility. The disruption of forest soil nutrient cycles disadvantages management utilization including sustainable landscape management [2].

Global environmental change involves a related sequence of biophysical, ecosystem and socio-economic alterations that damage life-sustaining abilities of the planet [3]. The current global change is caused by human transformation of the natural environment, but also by the reaction of human communities to the induced modifications. Human transformations of natural environment are concentrated in a critical zone. The critical zone is range among sphere interfaces on the Earth's surface, where human changes in structure, chemical composition, radiation balance and biodiversity extend [4]. The most vulnerable part of the terrestrial critical zone is composed of soil (pedosphere), which includes interfaces among atmosphere, hydrosphere, lithosphere and biosphere. For these reasons, the soil damage has been altering character of the entire ecosystem over a long period [5].

The most serious soil damage is due to land use modifications after deforestation. While mere forest felling only gives rise to reversible changes in ecosystem functions, the combination of forest felling with soil erosion or conversion for the need of subsequent management utilization generates irreversible ecosystem degradation. Deforestation is instantly followed by declining evaporation and soil loss. The imminent consequences of deforestation are gradually leading to the regional climate change, the loss of ecosystem recoverability and uninhabitable landscape [6]. Regional climate change is mainly caused by reduction of water cycle between the lower-lying areas with higher evaporation and the higher-lying areas with higher atmospheric precipitation in the catchment. The evaporation reduction after deforestation is not sufficient to create cloudiness to make surfaces cooler. Subsequent decrease in precipitation over the higher-lying parts of the river basin deepens water shortage as well as further evaporation decrease in the lower-lying parts [7]. The forest ecosystem recoverability loss is caused mainly due to depletion of the organic matter from the exposed soils, which stimulates germination of tree seeds by means of hormonal effects and moisture retention [8]. Ultimate landscape uninhabitability is caused by uncontrollable soil erosion as a result of surface exposure to wind and landslides of weathered rocks impoverished of organic binders [9].

Forest ecosystem restoration is made impossible within the recent global change, except for soil erosion by pollution. Nitrogen pollution from industry and agriculture has become a major environmental driver of the forest growth [10]. However, atmospheric pollution with the available nitrogen forms is manifested contradictorily within different soil types in forests. The forests situated on optimally fertile soils were generally favorably affected by nitrogen pollution while the predominant forests located on poor soils were damaged. On the one hand, adequate nitrogen intake supports plant growth and, on the other hand, it increases demands on other mineral resources which are declining as a result of human changes in the environment [11]. The unnaturally increasing disparity between plant demands and dwindling nutrient resources causes growth decrease and gradual ecosystem degradation even in hitherto unspoilt areas [12]. Even though the largest nitrogen deposition occurs in the vicinity of pollution sources with lower precipitation, higher concentrations of available nitrogen in wet deposition acidify ecosystems significantly. Approximately 70–80% of nitrogen released from industrial products falls back to the Earth's surface [13]. Of the nitrogen inputs, 5% penetrates the groundwater, 12%

is released into the atmosphere, 30% is immobilized in soil organic matter and 53% is removed with the crop. The utilization of nitrogen by the plant production is still declining, whereas the rate of nitrogen losses by leaching and gasification as well as immobilization in the soil increases in proportion to the amount of fertilizers [14]. Nitrogen supplied to the soil by means of fertilizers results in faster depletion of available bases, making the soil more susceptible to acidification [15].

The environmental nitrogen load is becoming an increasingly important driver of the global ecosystem change as it has exceeded the critical level in large areas of most continents [16]. Exceeding critical nitrogen loads extended plant susceptibility to drought [2, 17, 18]. The widespread plant susceptibility is compound of growing sensitivity of terrestrial ecosystems to climate change. Subsequently, the processes of the climate change and alterations in complex growth conditions for plant communities lead to a deviation in development of prospective natural vegetation or to biome alteration [19]. Therefore, the soil protection is becoming a tool to mitigate the effects of the global terrestrial change maintaining ecosystem link among forests, water cycle and human civilization [5].

2. Forest soil degradation processes

2.1 Impacts on self-organization

Soil degradation may be ranked to one of the most dangerous human activities on the Earth's surface because soil is not instantly renewable. Degradation commences with vegetation coverage damage as a result of which evaporation decreases. The evaporation diminution foreshadows regional warming which contradictorily results in an intensification of water cycle into short, intense rainfall more frequently accompanied by soil drift or even flash floods [20]. Soil degradation affects ecosystem self-organization. The disruption of soil self-organization is initiated with the decrease in the diversity of functional connections within microbial communities. Disintegration of soil functional interconnectedness involves biodiversity loss and substitution of symbioses for decomposers (saprophytes) that do not exchange available nutrients among organisms, but cause leakage of substances from the ecosystem [21]. Forest soil degradation destroys irreplaceable natural values that improve adaptability of cultural landscape to climate change [22]. The disruption of soil self-organization damages both the continuity of crop production and success of ecosystem restoration.

Soil degradation is divided into quantitative or qualitative one (**Figure 1**). Quantitative soil degradation represents the physical loss of a soil body. Qualitative soil degradation involves unfavorable alterations in soil physical or chemical properties that limit ecosystem functions [23]. Soil losses occur through claim, erosion or desertification:

- Claim is usually accompanied by soil sealing, where the land is either merely covered or removed and replaced with building materials. The claim completely destroys soil infiltration capacity. As a result of clearing, the radiation balance and heat capacity alter locally and surface runoff increases sharply [24].

- Soil erosion is surface soil drift by gravitational shifts, water or wind. The human activity has intensified soil erosion after vegetation removal, excessive grazing and inappropriate tillage, developments affecting landscape and pollution

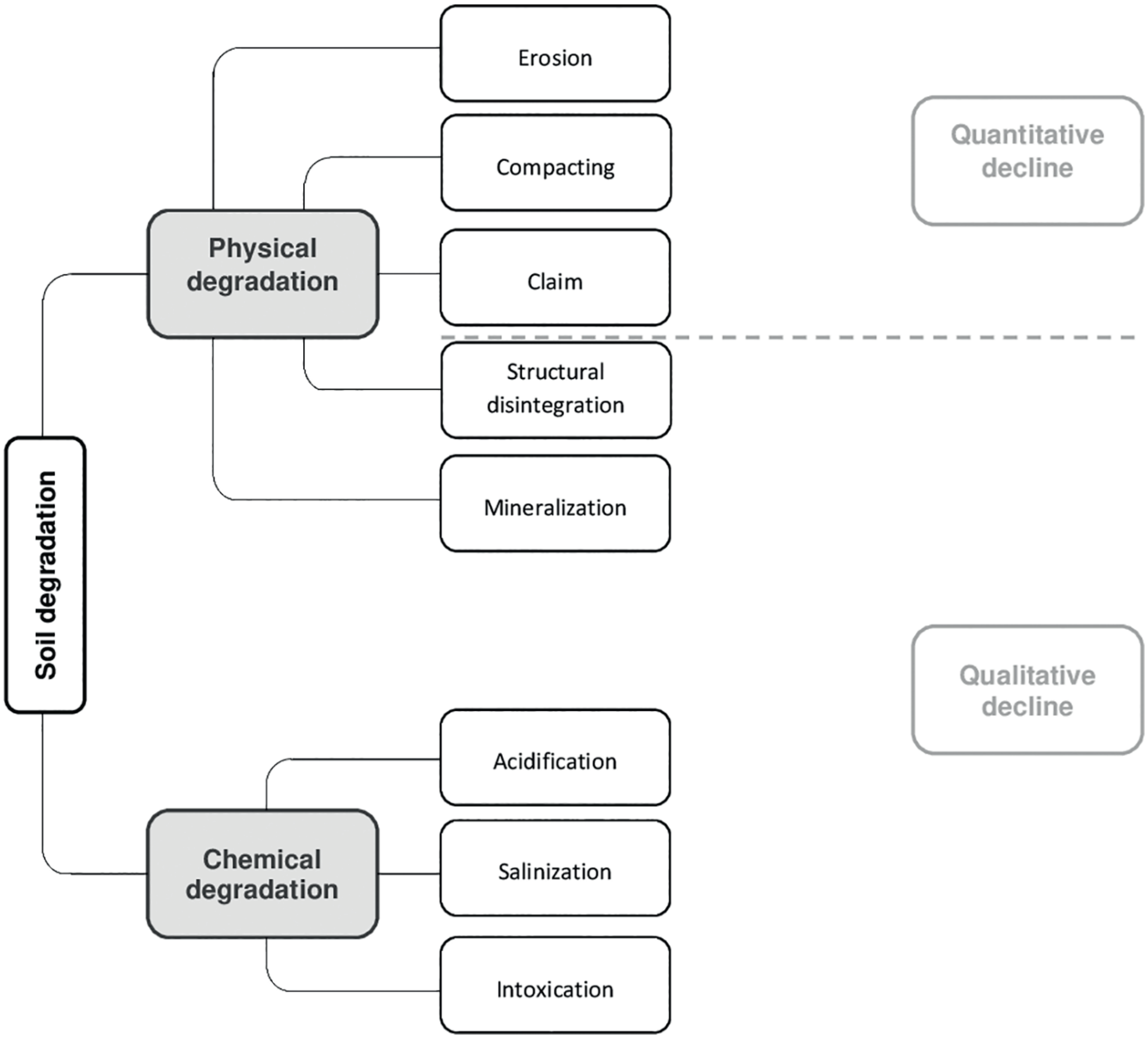

Figure 1.
Division of soil degradation processes along quantitative and qualitative impacts on physical or chemical properties.

which stopped formation of organo-mineral particles aggregating the soil into more cohesive peds (**Figure 2**). The vulnerability through erosion (erodibility) depends on weatherability of soil-forming substrate, soil cohesion, climate and land use (**Table 1**).

- Desertification is unnatural spread of wastelands after permanent vegetation removal. Causes of unnatural desertification are mainly disproportionate grazing, fires and erosion followed by loss of soil water retention capacity. Deserts spread the fastest in areas naturally adapted to seasonal drought [25]. Approximately 10–20% of the world's semi-deserts and steppes are threatened by desertification. The accompanying phenomena of desertification are decrease in groundwater levels or salinization which make it impossible to restore vegetation and lead to wasteland homeostasis [9].

Qualitative soil degradation is produced by excessive losses of the organic matter, the reduction of the biological activity, acidification, contamination, technological compaction (pedocompaction), technical or wind salinization and

Figure 2.
Coupled occurences of soil erosion and spreading of desert in arid environments seriously threat forest restoration due to water availability decrease.

Erodibility	Parent rock	Soil units
Very easy	Eolian deposits	Leptosols, Retisols, Anthroposols
Easy	Clayey shales, basaltic tuffs	Leptosols, Luvisols, Cambisols
Medium	Carbonate deposits, sandstones	Calcaric Leptosol, Chromic Cambisol, Ferralic Podzol
Medium hard	Breccias, graywackes, phyllites, andesites	Stagnic Podzol, Stagnosols, Stagnic Cambisol
Hard	Metamorphites, basalts, diorites	Gleysols, Stagnic Luvisol, Haplic Cambisol
Very hard	Igneous rocks, shales	Epi-humic Cambisol, Vertic Chernozem, Histosols

Table 1.
The vulnerability of forest soils by erosion (erodibility) along various parent rocks and developed soil units.

technical modifications of soil properties. Although qualitative soil degradation potentially occurs in much smaller areas than quantitative one and its effects are usually reversible, they have a similar overlap on landscape functions in the form of reduced water retention capacity and biodiversity, increased runoff and substance imbalances.

Degradation of forest soils is distinctive mainly to the qualitative damage. Qualitative degradation in forests prevails due to the long-term growth of continuous tree species communities. Tree species instantly impede quantitative damage to soils; on the other hand, periodic windthrows during storms mingle the mass among soil horizons, as well as move the soil down the slope. These post-disturbance movements

Figure 3.
A series of differently degraded soil bodies in mountain conditions: introskeletal erosion in Dystric Hyperskeletic Leptosol (A); surface scarification of Entic Podzol (B) and accumulated Spolic Garbic Urbic Technosol (C).

of earth bodies divide microrelief and homogenize soil properties, but at the same time their arrangement is concentrated along the effects of individual global climate changes [26]. However, predominant qualitative degradation of forest soils is manifested by deterioration of physical or chemical properties of solid soil bodies due to external human activities (**Figure 3**) [27].

Deterioration of forest renewal as a consequence of qualitative soil degradation commences with fertility change. Forest felling is accompanied by accelerated leaching of nitrogen substances which can only be ceased by sufficient available calcium [28]. Leaching is preceded by increase in C/N which indicates decrease in ability of soil organic matter to bind mineral nutrients. Soils damaged by compaction of the profile middle part, texturally significantly differentiated or hydromorphic, are exposed to a slow-motion water flow, which expels air for the root growth and similarly increases C/N [29]. The root systems grow merely shallowly with water stagnation and the nutrient loss, making forest stands more susceptible to soil moisture fluctuations [30]. Thus, felling of forests threatened by qualitative erosion impairs the ecosystem ability to restore as a result of exposure to episodic drought [2].

2.2 Physical degradation

Degradation of soil physical properties includes structural damage, pore loss and compaction. The processes of physical soil damage result in both loss of water retention capacity and humus loss by introskeletal erosion. The decline in soil water retention capacity is usually caused by repeated heavy machinery moving. Heavy machinery moving worsens soil aeration and water permeability. Reduced aeration is reflected in the decrease of blank spaces for plant roots and the consequent reduction in the biological activity.

Forest soils are less endangered by physical degradation than agricultural ones owing to dampening effect of surface humus. Nevertheless, topsoil compaction can initiate introskeletal erosion. The mechanical degradation threat is descending from Histosols and gleyed soils to granularly light drying soil bodies [31]. The risks by mechanical damage to the forest soils vary along the grain-size composition, relief exposure and groundwater level (**Table 2**) [32].

Risk	Soil series	Inprint depth	Consistency	Critical pressure (kPa)	
				Dry conditions	Wet conditions
Very high	Histosols+Gleysols	≥35	Cohesionless	30–50	5–12
High	Stagnosols+stagnic soil groups	25–35	Viscous	50–140	12–22
Medium	Stagnic Cambisols-Stagnic Luvisols-Fluvisols	15–25	Crombly	140–300	18–50
Moderate	unhydromorphic Cambisols+Luvisols+Chernozems+Regosols	7–15	Cohesive	300–600	50–80
Insignificant	Leptosols+Podzols	<7	Skeletic	600	80–120

Table 2.
Characteristics of forest soil compaction risk after logging machinery movement.

- A very high risk results from high groundwater level and incoherent soil-forming substrate. Forests endangered by a very high risk of soil erosion are mostly found on Histosols or Gleysols, but also on water-affected Luvisols, Arenosols or Podzols.

- A high risk emerges from extremely developed hydromorphic features related to heavy skeletality of soil bodies. Forests exposed to high erosion risk are covering Planosols, Stagnosols and Gleysols, including gleyed subtypes on clayey shales or claystones the most.

- A medium risk is associated with the medium level of forest site gleyfication. Forests at the medium soil erosion risk are located on Stagnic Cambisols, Stagnic Luvisols or Stagnic Fluvisols.

- A moderate risk is related to site desiccation. Forests moderately endangered by erosion means may be found on Cambisols, Luvisols, Chernosols or on Fluvisols developed from sandy substrates.

- An insignificant risk is conditioned by soil cohesion, medium skeletability and merely slightly by sloping relief. Forests insignificantly exposed to soil erosion occur at unexposed sites constituted by Leptosols, Cambisols, Podzols or by Chernosols.

Introskeletal erosion represents a predominantly vertical subsidence of fine-grained soil particles through blank spaces among skeleton to the base of rock mantle. The introskeletal erosion risk resides in unstable occurrence of surface humus. Introskeletal erosion is triggered after removal of the vegetation cover in the exposed sites. Its result is the loss of whole fine-grained matter, followed by impossibility of restoring plant community and permanent exposure of relief [33]. The threat to the site by introskeletal erosion is distributed along exposure of relief and soil skeletability [34]:

- An extreme risk accompanies periglacial brash in arcto-alpine conditions. Extremely endangered sites are only merely sparsely populated by forests. Emerging plant communities are very sensitive to any changes in growth conditions, so they require consistent protection.

- A very strong risk accompanies shallow soils. Forests endangered by very strong risk of introskeletal erosion are most frequently found along upper tree vegetation limit that is sensitive to global warming [35].

- A strong risk is accompanied with brash or stone fields (**Figure 4**). Forests exposed to the strong risk of introskeletal erosion are mostly concentrated on long rocky slopes below the upper limit of tree species vegetation.

- A medium risk is characteristic of islet occurrences of brash on rocky slopes. Forests exposed to the medium risk of introskeletal erosion typically occur in the middle parts of mountain ranges.

- A low risk is specific for sparse outcrops of subsoil decay on medium rocky slopes. Forests threatened by erosion on a small scale occur on gentle slopes with deeply developed soils

2.3 Chemical degradation

2.3.1 Acidification

Degradation of soil chemical properties is the intensification of naturally processed weathering and substance leaching. Chemical soil degradation includes acidification, salinization and intoxication. Acidification is the most extensive process of forest soil degradation causing decline in site fertility [36]. Soil acidification is gradual decreased in neutralizing capacity. In nature, acidification is elicited mainly by water autoprotolysis, naturally acid atmospheric precipitation, organic acids activities, but also by formation of strong acids after reactions of water with atmospheric gases (CO_2, SO_2) or with some rock-forming minerals (chlorides, sulphates or carbonates). The resulting acids (formal HCl, H_2CO_3 and H_2SO_3) can cause very intensive decomposition of original minerals into salts [37].

The intensification of soil acidification was caused by fertilization, crop cultivation and industrial pollution. Industrially emitted CO_2, SO_2 and NO_x create formal acids and soil bases are excessively depleted to neutralize them. The base loss slows down humus formation; on the other hand, raw humus is a significant source of organic acids. The slow-motion formation of humus is reflected in decrease of organo-mineral colloid genesis as a result of which the number of binding sites for exchange cations on the active surfaces of soil particles decreases. The decomposition of variable organo-mineral colloids limits base cations exchanges to stable mineral colloids. Nonetheless, mineral colloids can capture only 0.2–25% of exchangeable cations, unlike organic particles [38].

The soil resists acidification impacts by exchange reactions between inputs of acid-forming H_3O^+ and available sources of releasable cations. Soil cation sources are

Figure 4.
Introskeletal erosion leaves rocky flows without surface humus instead soil, where plants can to root hardly, thus forest site gets features of disperse platforms with dwarf vegetation.

active depending on pH (**Figure 5**). Intensified acidification of forest soils is naturally slowed down either by deciduous tree species or by weathering of the soil-forming substrates. The influence of tree species predominates in surface soil horizons while the influences of soil-forming substrate predominate in the subsurface horizons. Significant acidification in surface horizons of forest soils most often affects the transitional ecosystem types [39]. Even though the mitigating effect of tree species does not overcome impacts of weathering, the optimal tree species composition actively

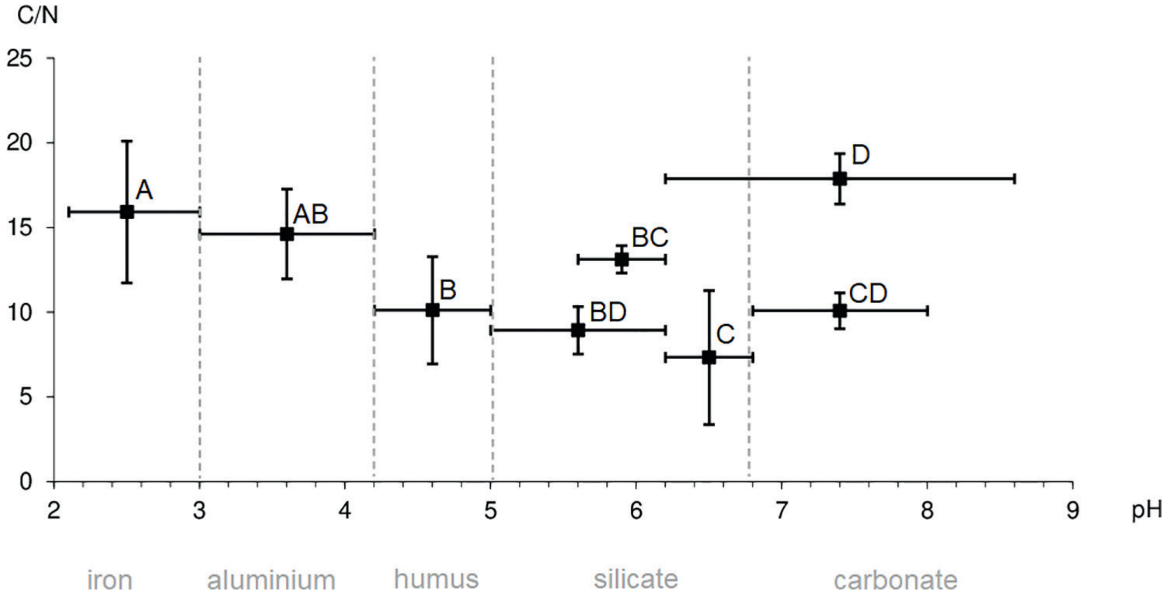

Figure 5.
Intervals of soil acidity (pH) and organic matter C/N ratio divide trophic (A – Oligotrophic; AB – Oligomesotrophic; B – Mesotrophic; BC – Mesotrophically nitrophilous; C – Nitrophilous; CD – Nitrophilous-base; BD – Mesotrophically base; D – Base) series among zones buffering acidification through specific neutralization. Data according to [39].

reducing C/N prolongs weathering effects. On the other hand, soil cation release by weathering maintains intensified acidification as a reversible process. Weathering counteracts acidification by means of electrochemically controlled soil-forming substrate decomposition [12, 40, 41]:

1. **The carbonate zone** (pH > 6.8) is employed by dissolving the CO_3^{2-} compounds, whereby the incoming H^+ is neutralized into soluble salts. The consequence of these acid–base reactions is a gradual loss of carbonates by dissolution and leaching, which can only be forestalled in soils formed directly from carbonate substrates and rocks.

2. **The silicate zone** (pH 5.0–6.8) occurs either within soils from which carbonates have already been leached or where silicates predominate. Acids cause decomposition of silicates from which base cations are released and deuterogenous clay minerals are formed.

3. **The exchange zone** (pH 4.2–5.0) may be found in those soils where there is a disproportion between base cations released during weathering of silicates and H^+ inputs. The excess of entering H^+ is trapped on surface of organic colloids to release bases.

4. **The aluminum zone** (pH 3.0–4.2) subdues effects of acidic inputs by releasing Al^{3+} in the presence of sesquioxides with simultaneous formation of organic complexes. Soil fertility decreases, nutrients are further leached and the biological activity decreases.

5. **The iron zone** (pH < 3.0) occurs in those soils where acidic inputs are subdued by the dissolution of iron oxides, Fe^{3+} migration and destruction of clayey minerals. Nutrients are excessively leached out from these soil bodies, the concentration of toxic substances in soil profile increases and the biological activity is usually concentrated only into raw surface humus.

The unnatural decomposition of soil minerals triggers irreversible acidification. Acidification may be mitigated merely after the removal of acidifying substances sources. The acidification of forest soils affected exchange zone the most, switching to active aluminum zone [42]. The damage to the forest ecosystem by release of active Al^{3+} followed due to occupation of exchange sites on soil particle surfaces instead of bases, the lack of which limited root growth. The roots were concentrated shallowly below the surface so that new focal points of biological activity and humus ceased to form deeper in the soil [43]. Introducing the other side of the fact, the marginally widespread transition from the aluminum zone to iron one was ensued by loss at the ability of forest ecosystems to restore from the damage (**Figure 6**).

Air pollution has significantly accelerated soil acidification, especially in the areas of forests transformed into homogeneous stands of coniferous tree species. While cultivation of homogeneous coniferous forests homogenized formation of acidic humus causing micropodzolization and increased base cation leaching, the pollution after acid deposition reduced not only the forest increment but also decomposition of organic matter [44]. Forest increment was reduced by direct damage to the assimilation apparatus, by stimulating sensitivity to seasonal drought or frost and by reduction in soil symbioses mediating nutrient deficiencies. The decline of mycorrhizal

Figure 6.
Irreversible damaged forests are characteristic by predominantingly dead tree storey and by absent young woods due to lost soil organic matter irreplaceably stabilizing moisture during seed germination.

fungi was followed by increase in frequency of saprophytic to saproparasitic fungi, which diverted organic matter decomposition to complete leaching from the ecosystem [45]. The susceptibility of mycorrhizal symbioses to pollution resulted in limited accessibility to phosphorus necessary for nucleic acid synthesis [46]. The disturbed phosphorus cycle triggered decrease in increment as well as seed germination leading to forest self-organization loss [47].

2.3.2 Salinization

Soil salinization is the process of accumulating surpluses of mineral salts. Salinization of forest soils is a rare phenomenon, but it threatens 23% of agricultural land, mainly in arid areas [48]. Forest soils are salinized in areal or linear extent. Areal salinization is caused by high groundwater mineral levels, the use of saline water for irrigation, waste materials for fertilization or deposition of solids. Linear salinization occurs alongside roadsides maintained by chemical salting during winter or along river banks. The recent climate change is expanding areas of salinized soils with rising sea level along the coast or estuaries. On the other hand, the natural risk of soil acidification subdues consequences of salinization [49].

The impacts of salinization in forests are associated with extreme soil chemical properties. Salinization highlights malfunctions of water and nutrient uptake by plants. Above all, the disproportionate sodium input (sodification) disrupts ration among exchangeable bases in the soil environment, thereby disrupting effects of alkalization on soil structure. Significant Na^+ inputs displace other cations from soil sorption complex and disperse soil particles. Sodium displacement of cations results in deficient nutrition, but at the same time crushes soil structure, thus water availability fluctuates. Sodium surplus in plant tissues reduces osmotic pressure, whereby cells lose ability to absorb other substances from soil solution [27]. While conifers are susceptible to soil salinization, deciduous tree species are tolerant to it. The younger plants are more susceptible than the older ones.

Areal forest salinization is most at risk in floodplains due to variability of water flow. The regulation of water flow caused groundwater level fall in some river basins while it resulted to water level permanent increase in some other ones. The groundwater level decline was typically ensued by ecosystem desiccation due to the fact that riparian forests are mostly located in submontane locations with insufficient precipitation [50]. By contrast, rising groundwater levels after water regulation meant change in availability of mineral ions, with impacts on soil microbial activity and ability of the ecosystem to sequester carbon. The increase in level of saline water inflicts decrease in soil microbial activity and consequently decrease in vegetation growth [51]. On the one hand, decreases in growth processes are caused by loss of oxygen in soil environment, on the other hand, by increasing concentrations of Na^+, Cl^-, SO_4^{2-} ions, including Fe and Mn compounds. In particular, SO_4^{2-} in the soil solution is converted to toxic sulphide when there is a lack of oxygen. Although Fe and Mn are biogenic elements that catalyze soil organic matter decomposition, bound in sulphides block microbial metabolism [52]. The main forest salinization danger with groundwater is inability to adapt on climate change due to spread of microaerobic conditions [53, 54].

2.3.3 Intoxication

Intoxication of soils with heavy metals, radioactive or petroleum substances is a rare but very hazardous process of cumulative pollution. Especially, heavy metals merely slowly participate in biogeochemical cycles and accumulate in the ecosystem because they are either microbiogenic (Cu and Zn), or xenobiotic (e.g. Cd, Co, Pb, Hg, Ni).

Soil intoxication occurs by deposition means. Sources of cumulative pollution are point or dispersed ones. The point sources of heavy metals are smelters, thermal power stations or municipalities by watercourses. The dispersed sources are represented by polluted water, inappropriate distribution of industrial or sewage sludge or operation of internal combustion engines. Fluvisols, which are among the most intoxicated soils, are usually located between watercourses and agricultural soils [48].

Xenobiotics are toxic to most organisms. They mainly affect energy balance of living cells and their division. Heavy metals mainly bring about halting respiration as a consequence of interactions with SH- groups at intracellular enzymes and their complexes, they disrupt semipermeability of cell membranes and their proton gradient. Soil environment pollution with heavy metals significantly reduces density of microbial occurrences and directly damages plants. The rate of soil contamination damages microbial activity significantly more than the differences in heavy metal contents among different sites [55]. However, the decline of susceptible species is being replaced by expansion of resistant species populations, including pests abundantly infesting damaged plants [56].

Resistant phytophagous arthropods adapt to the environment contaminated with heavy metals by searching for less contaminated nourishment, sufficient release of metals in excrements, by sloughing or by means of other tissues (in the adipose body, epithelium of the digestive tract) [57]. The importance of phytophagous insects for the movement of heavy metals in ecosystem lies in the fact that these invertebrates are an important link in food web that receive toxic substances directly from plants, especially Cd and Zn [58, 59], but no Ni and Fe [60].

The risk of heavy metal accumulation with toxic manifestations threatens not only tree species, but also predators. Numerous ground beetles (Carabidae) and ants (Formicidae) are mainly food-bound to phytophagous insects, earthworms, countless larvae and springtails [61]. On the other hand, the immobilization of heavy metals takes place in cells of specialized metallogeneic microorganisms by binding to metallothionein-based amino acids. Immobilization of heavy metals in amino acids changes course of humus formation. The rate of biosorption on the soil microbial active surfaces typically decreases in order Zn > Cd > Pb > Cu > Cr [62]. Alterations in the forest ecosystems as a result of heavy metal pollution include (**Figure** 7):

- the reduction of phospholipid fatty acids content in the bacterial cells and raw humus. Even though the total content of phospholipid acids is directly proportional to ATP synthesis, it decreases under the toxic load. The consequence of these processes is alterations in overall functional diversity of microbial community and inability to decompose deposition by aromatic hydrocarbons [63].

- promoting release of mobile humus substances and decrease of insoluble substances. On the other hand, the great ability of Pb to form complexes with insoluble humus substances maintains its immobilization while Cd and Zn tend to form soluble complexes. Although more heavy metals are bound to soluble humus substances than to insoluble organic compounds, the greater release of soluble compounds also contributes to pollutant migration in the soil and to their penetration into groundwater [64].

Petroleum products belong to secondary persistent organic compounds, similar to benzo(a)pyrene, polychlorinated dibenzo-p-dioxins or dibenzofurans, which are removed from the soil for more than 2 years [65]. Like benzo(a)pyrene, they consist of polycyclic aromatic hydrocarbons that directly harm the health of organisms. Oil pollution is significantly more caused by human activity than by natural (geogenic) sources. It begins with mining, combustion of petroleum products (fossil fuels), accidental or operational spills and corrosion of industrial materials. Oil products in the forest ecosystem load surface humus the most, which at the same time prevents their

Figure 7.
Forests dying at regions loaded by acid deposition were transformed to substitute stands of resistant introduced tree species which have provided cover for regeneration of indigenous forest communities after pollution decrease.

penetration into deeper occurring soil. The load of surface humus decreases activity of soil microorganisms. The decrease of soil biological activity is mostly caused by aromatic nuclei imitating lignin, which either block formation of amino acids or replace carbon compounds in fungi [66]. Subsequently, the humus decomposition is disrupted, foreshadowing disruption of processes to get available nutrients from the soil. Nevertheless, the load of petroleum substances is irregularly concentrated in surroundings of industrial areas and vertically along different intensities of wood logging in floodplains, hillycountries, highlands and high-mountain forests [67].

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