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The Ore Mountains: Will Successive Recovery of Forests from Lethal Disease Be Successful?

The Ore Mountains (the Krušné Hory Mountains) are located in Central Europe on the border between the Czech Republic and Saxony, Germany. They are known as an area where air pollution has had a very severe impact. Sulphur dioxide, produced mainly by coal power plants and the chemical industry, caused extensive decay of forests in the upper part of the Ore Mountains during the 1970s and 1980s. Dying trees were felled on more than 40,000 ha. Stands of mainly substitute tree species, considered to be more resistant to air pollution, were established on these locations. With the desulphurization of the main pollution sources and the decrease in industrial production, pollution significantly diminished during the 1990s. Nevertheless, even in the second half of the 1990s, distinctive damage to substitute forests was observed. A survey of their condition detected about 1600 ha of white birch stands in decline, 53 ha of blue spruce stands affected by needle yellowing, and prevalent damage of mountain ash by red deer. Our comprehensive studies closely observed the situation in the Ore Mountains and focused on practical questions and solutions to current forestry problems. We proposed appropriate measures relating to changes of tree species composition, forest plantation, silvicultural principles, and amelioration of forest soils, taking into account the current level of pollution, the condition of forest soils, and the vitality of forests. Several options, including a rough economic evaluation, are presented here.

Forestry in the Ore Mountains and the history of air pollution

Most of the Ore Mountains area is covered by forests, totaling more than 110,000 ha on Czech territory (Figure 1). Human exploitation of natural forest started here as early as the 12th and 13th centuries due to the expansion of mining activities and the building of new settlements. Excess cutting commonly endangered the supply of wood for mines, so the first law on forest protection was adopted during the 16th century. Forests did not really recover until the Thirty Years' War (1618–1648). At the beginning of the 20th century, forestry focusing on timber production in Norway spruce stands was predominant. The changed tree species composition was reflected in less stable forests and frequent wind and hard rime damage. Since the Second World War, air pollution has been the driving force in forest management, peaking during the period of forest decline in the 1970s and 1980s. About 75% of the forests in the Ore Mountains are currently owned by the state; the rest are communal or private forests.

The air pollution load culminated in the late 1980s; damage to forests, however, was observed even in the subsequent period. In the winter of 1995–1996, a high level of pollution accumulated during an atmospheric temperature inversion that occurred over a period of more than 3 months. This resulted in more than 10,000 ha of severely damaged spruce stands. In the spring of 1997, white birch—a major species in the "substitute forest stands"—declined on more than 3000 ha. The reasons are not entirely clear, but it seems that climatic stress played an important role in this phenomenon. Currently, sulphur dioxide does not threaten the vitality of the forest stands directly, but forestry in the Ore Mountains region is facing difficulties. The forest stands of substitute tree species are often characterized by lower ecological stability, limited environmental functionality, and negligible productivity.

The situation was closely observed by Forests of the Czech Republic—a state-run enterprise responsible for the management of state forests—and by the state authority in charge, the Ministry of Agriculture of the Czech Republic. Their common interest resulted in a project, Forestry Management in the Air Pollution Area of the Krušné Hory Mountains, financed by the Grant Agency of Forests of the Czech Republic. Moreover, 2 comprehensive studies were funded by the Ministry of Agriculture, focusing on the current condition of the substitute tree species stands and on game management in the Ore Mountains. This project, and both studies, focused on practical questions and on solutions to current forestry problems. A broad team of scientists, forestry experts, and practicing foresters took part in the investigations, including representatives of several research institutes, 2 forestry universities, and forestry management.

Survey of current conditions

The fundamental goal of the project was to evaluate the current state of air pollution, climatic factors, forest vitality, and forest soil properties. A long-term series of measurements demonstrated that acute risk of "traditionally" harmful substances such as sulphur dioxide, fluorine, or nitrate oxides is not so significant today. By contrast, ozone concentrations are considerably higher, reaching average values of more than 100 μg m^{-3} during the vegetation season. Such values are common today in the Central European mountains. In the Ore Mountains area, the visible ozone damage is mostly irregular and mainly affects broadleaved tree species. It can be expected, however, that forest trees' resistance to abiotic and biotic stressors will be lower due to ozone. Forest stands in the Ore Mountains are still partially affected by meteorological stresses that result from disturbed meso- and microclimatic conditions created by the vast clear-cuts carried out in the 1970s and 1980s, as well as by late and early frost and waterlogging. As new forest stands grow, the importance of these factors decreases. On the other hand, damage by hard rime and strong winds, which have been typical in this area for centuries, will increase.

The limiting factor in improving the vitality of forest stands in the Ore Mountains is the current degradation of forest soils. The soils were affected for a long time—and to varying degrees—by atmospheric deposits, changes in species variety and forest stand structure, the use of various technologies for site preparation for reforestation—including the removal of litter and mineral horizons by bulldozers on some sites—and by various procedures of chemical reclamation. These factors resulted in highly heterogenous soil prop-

FIGURE 1 The Fláje water reservoir in the Ore Mountains region. This extensive forested area and others in the region are an important source of freshwater. Forests fulfil the function of water protection. (Photo by M. Slodičák, 2007)

FIGURE 2 Stands of substitute tree species in the Ore Mountains are mostly composed of birch and blue spruce. (Photo by M. Slodičák, 2007)

erties and low spatial dependency. Despite the radical decline in sulphur production, it is not possible to expect a rapid remedy for forest soils. Mainly due to nitrate deposition, the critical load of acid deposition in coniferous stands is currently exceeded in 87–90% of the Ore Mountains area.

At present, substitute tree species occupy approximately 36,000 ha of the forest area in the Ore Mountains (Figure 2). The most common species in these stands is birch (*Betula* spp.), which covers more than 12,400 ha, followed by blue spruce (*Picea pungens*) on more than 8800 ha, larch (*Larix decidua*) on 6570 ha, mountain ash (*Sorbus aucuparia*) on 3100 ha, and alder (*Alnus* spp.), mountain pine (*Pinus mugo*), and others. Some of these forest stands (mainly white birch) suffer from meteorological stresses, root-system deformation (blue spruce and larch), disturbed nutrition, and attacks by biotic agents, amongst which the damage done by red deer to mountain ash is quite significant.

Recommendations for forest management

Reconstruction of substitute forests

Because of weakened stability and poor environmental and productive functions, the forest stands of substitute tree species, which played a role in the heavy pollution period during the 1970s and 1980s, have to be replaced by "target" tree species that are ecologically reasonable and can also fulfill a productive function—such as the Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*), silver fir (*Abies alba*), or sycamore maple (*Acer pseudoplatanus*). But until this species conversion can take place, individual stands of substitute species should be protected, because they create appropriate micro-climatic conditions that are essential for the introduction of sensitive species such as beech or fir. The conversion has already started on sites with severely damaged substitute tree species stands. In order to convert the substitute tree species stands, 3 alternative forms of species composition are proposed:

1. Target tree species composition on sites of improved environmental quality (Figure 3);
2. Temporary bio-ameliorative tree species composition based on broadleaved species to improve site environmental quality and forest soil quality;
3. Preparatory species composition as an intermediate option to the other 2 alternatives.

Preparatory species composition is based on a lower initial density of planting stock and small-area fenced enclaves of selected beech cuttings that lead to the formation of genetically high-quality beech stands with anticipated earlier mast year occurrence at the age of 50–60 years. This expected natural regeneration should help to achieve the required balance of broadleaved species and enhance the diversification of stand structure.

The target tree species are recommended mainly for sites with acid deposition of less than double the critical load, ie up to 3.2 kmol H^+ ha^{-1}. For different localities, 2 other variants are proposed. For each forest type, defined according to its environmental properties, particular tree species composition in each of the 3 mentioned variants is delineated. The rotation period of coniferous stands threatened by acid deposition should be shortened, while in beech stands it can even be prolonged. Moreover, in spruce stands devalued due to rod peeling by red deer, a shortening of the rotation period is an appropriate management measure.

Planting and quality of plants

With regard to the planting stock, morphological and physiological quality standards must be followed. For Norway spruce, use of bare-rooted seedlings grown in forest nurseries with a climate corresponding to a minimum altitude of 500 m is recommended. For broadleaved species, use of containerized plants is suggested, with increased attention to avoidance of root-system deformation. Attention should be given to root-collar diameter, root/shoot ratio, and root quality. On the other hand, a greater difference in plant height is permissible. For the purpose of under-planting, planting stock with shade tissues should be used which is able to adapt faster to these specific conditions.

Thinning of the stands

For the main timber tree species—Norway spruce, European beech, larch, and their mixtures—thinning models are recommended. Stand segmentation, with a skidding track of 4 m width, should be established in a timely and proper manner. Thinning models for stands with prevail-

FIGURE 3 The wet and cool climate of the Ore Mountains is very suitable for the regeneration of Norway spruce. (Photo by M. Slodičák, 2006)

FIGURE 4 In the western part of the Ore Mountains, most of the forest still has a high economic importance. (Photo by J. Novák, 2006)

ing Norway spruce are based on very heavy thinning at a top height of 5–7 m. Damaged trees should be preferentially removed by negative selection. At the same time, admixture of shade-tolerant broadleaved species is proposed. Heavy thinning increases stability with respect to snow, hard rime, and wind damage; it also stimulates radial increment, decreases the deposition load, and results in better litter decomposition. For larch, positive selection thinning is recommended in stands of high quality, to avoid excessive breakage of the canopy; in stands of lower quality, negative selection is appropriate. The environmental functions of larch stands are to be supported, including underplanting with beech in enclosed areas of the stands. For beech a first thinning is recommended in stands with a height of 4 m, followed by 6 interventions in quality stands, and 4 in lower quality stands. The first thinning should focus on negative selection; later, positive selection of dominant trees should be performed.

Amelioration of forest soils

As mentioned above, the quality of forest soils could be a limiting factor in forest management in the Ore Mountains region. Methods for biological and chemical amelioration of forest soils are proposed, based on a survey of soil conditions. Procedures focus on regeneration of the long-term function of the soil environment and sufficient nutrition of forest stands at the stage of rapid biomass increment (stands of medium age). Biological amelioration is based on a higher proportion of broadleaved species, including pioneer species such as mountain ash, alder, and willow. By comparison with Norway spruce stands, these species can help decrease the amount of acid deposition; they also have a positive influence on litter decomposition and nutrient cycles. On sites with more pronounced acidification and pure base cation stock, a combination of fertilizing measures with liming is necessary. When selecting plots for liming or fertilizing, several criteria—including soil chemistry, forest stand quality, nature protection, and watershed area—must be taken into account.

Reduction of game stock

Another problem that affects forest regeneration in the Ore Mountains is the unbalanced relationship between game and the forest ecosystems. Red deer have a particularly negative effect when it comes to converting substitute tree species stands to stands with target species composition—one of the alternative forest management methods recommended above. Indeed, damage by red deer (browsing, bark stripping, and bark browsing) causes a significant decrease in biodiversity and an unacceptable economic loss in forest productivity. In fact, the whole 110,000-ha forest area suffers from constant attacks on ecosystems by game. Consequently, the yields of future stands are expected to decrease by EUR 192 million per rotation, ie the annual financial loss could easily be EUR 1.6 million (for a rotation of 120 years). Therefore, in order to ensure successful forest regeneration and appropriate forest productivity (Figure 4), significant reduction of game stock and emphasis on proper game management are absolutely appropriate requirements.

Conclusions

According to a rough economic evaluation—calculating expenses and income for the next 30 years of secondary stand transformation in the Ore Mountains region—the whole forest regeneration project will require substantial financial allocations. Based on the above-mentioned composition alternatives, financial needs for 3 silvicultural scenarios were assessed:

- Reconstruction preferring "target" species would require approximately EUR 182 million;
- Reconstruction using bio-ameliorative species composition in the whole area would require EUR 223 million;
- The less intensive scenario is based just on reforestation of "hotspot" sites with declining substitute forest, according to current forest law, but it would still require as much as EUR 143 million in the next 30 years.

These extremely high financial requirements clearly cannot not be covered by private forest owners; nor can communal forest management take over such a burden. Therefore, some form of state subsidy needs to be granted. It is hoped that the responsible bodies—the Ministry of Agriculture and the Ministry of the Environment of the Czech Republic—will react positively. On the one hand, the current problems are a "heritage" of a long history of industrial pollution in this region. On the other hand, if we include an estimate of the benefits of the environmental and social functions of reconstructed forest stands and weigh them against the costs of the environmental risks of leaving the forests as they are now, the overall balance is definitely positive.

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