JOURNAL OF FOREST SCIENCE, 51, 2005 (11): 519–525

REPORT

Conversion of substitute tree species stands and pure spruce stands in the Ore Mountains in Saxony

S. Hering, S. Irrgang

Landesforstpräsidium, Department of Silviculture, Central Forestry Department of Saxony, Graupa, Germany

ABSTRACT: The original natural forest ecosystems of the Ore Mountains (Norway spruce, silver fir, and beech forests) have been destroyed by overcropping since the 11th century. In the 19th century spruce afforestations on large areas were intended to meet the steadily increasing demand for timber. They led to the introduction of planned forestry by building up spruce age-class forests. Efforts of a few forest specialists to establish an ecologically adapted silviculture failed before long due to economic necessities. The paper presents the results of a complex experimental plot system aiming at the forest conversion in the Ore Mountains. Answers are given particularly to problems of the upper stand treatment for regeneration and of appropriate ways of soil preparation and planting. A network of forest climate stations and a broad variety of ecophysiological and yield investigations provide the basis for conclusions on light, temperature, soil, and water demand by regenerated tree species.

Keywords: substitute tree species stands; pure spruce stands; species composition conversion; Ore Mountains Mts.; Germany

The Ore Mountains are the largest of all Saxon highlands. The southern part is located in the Czech Republic.

The Ore Mountains belong to the transitional climatic zone from maritime to continental tendency. In the higher mountain and ridge ranges (700 to 1,200 m) the mean annual temperature of 4 to 6°C is a major limiting factor to plant growth. Sites endangered by frost are widespread. The annual precipitation ranges between 700 and 1,200 mm. The most frequent bedrock is gneiss. Thus, soils are relatively poor in nutrients and acid from their very origin.

Already in the 11th century people began with ruinous exploitation of natural forests. The Ore Mountains became a centre of ore mining and industry. At the beginning of the 19th century the forests were in a very bad condition. At this time the controlled forestry management began. The low covered forests were afforested. Norway spruce was planted in monocultures because of the increasing demand for timber. However, the monocultures of conifers were not stable enough against wind and snow breakage, pest attacks or air pollution. At the end of the 20th century air pollution caused the dieback of coniferous forests on a vast area. High values of sulphur dioxide from power stations on the basis of brown coal combustion in connection with extreme climatic conditions, especially in the upper mountain ranges, were responsible for this unprecedented ecological breakdown.

Air pollution led to catastrophic damage because Norway spruce was planted not only in the natural Piceeta of montane and subalpine altitudes but also and even more as pure stands at lower altitudes with their original predominating deciduous mixed forests. Approximately 90 square km of spruce stands died and were cut clear during the period from 1962 to 1991 (Hering 1993). Further 30 sq. km of spruce stands were lost after a long frost period and high immission loads of SO_2 in the winter of 1995–1996.

About 48% of this area were reforested with immission-tolerant, non-indigenous coniferous species such as larch, blue spruce, Serbian spruce and lodgepole pine. These species are suitable for planting on large clear-cut areas. They were also acceptable for reforestation under high loads of SO_2. The aim was to preserve the forest as an ecosystem with all ecological functions such as soil protection, regulation of water regime and shelter.

Norway spruce was planted on 31% of the area, especially in lower mountain ranges. Stands of birch (*Betula* spec.) and European mountain ash (*Sorbus aucuparia* L.) arose from succession on 8% of the area. Broad-leaved trees like beech or sycamore (*Acer pseudoplatanus* L.) could not survive under the extremely difficult climatic conditions typical of the large clear-cut areas.

Spruce stands have only survived in the western parts of the mountains and, in addition, at medium and lower altitudes. However, their canopy was opened up, and many stands suffered from severe bark peeling by red deer. Due to dense overgrowing with grass and strong game population, natural regeneration almost came to an end.

Current situation

The situation of air pollution has changed during the last years. Sulphur input has considerably fallen whereas nitrogen input has increased. Thus, the acidification of forest soils is becoming a problem. Therefore, soils are limed; about 160 sq. km of Saxon forests are treated every year.

The forest stands which are composed of the so-called substitute tree species are in good shape. However, they are artificial and ecologically unstable ecosystems. Therefore, the long-term target consists in restoring ecologically stable mixed forests with a substantial proportion of tree species of natural forest ecosystems. The stands of substitute tree species create conditions favourable for the successful reintroduction of original tree species such as beech, sycamore or silver fir.

Pure spruce stands which have survived in the western part of the Ore Mountains or at medium and lower altitudes regenerated their canopy during the last years. Under extreme weather conditions that occurred in the dry summer of 2003, however, large-scale pure stands were clearly susceptible e.g. to bark beetle tending to mass propagation. Accordingly, forest conversion must be urgently advanced in order to turn these pure spruce stands into stable forest ecosystems consisting of a mixture of site-adequate tree species.

Conversion of stands which are composed of substitute tree species

More than 30 coniferous species were included in the reforestation of the damaged areas since appropriate growing experience was available only for a few species. The choice of the provenance was often decisive for the outcome.

The following species were chosen most frequently:
- European larch (*Larix decidua* Mill.), Japanese larch (*L. kaempferi* [Lamb.] Carr.), and their hybrids,
- blue spruce (*Picea pungens* Engelmann var. *glauca*),
- lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.),
- Serbian spruce (*Picea omorica* Purk.).

Not all the stands can be converted simultaneously. Therefore, grading is based on stability criteria depending on site and prospective yield (Hering 1999).

Conversion is most urgent for stands of **blue spruce**. In most of them conversion is already under way since the young stand stage up to a height of 5 m is most suitable for this measure.

Blue spruce is very tolerant to sulphur dioxide and extreme climatic conditions. But the stands are growing slowly. Single trees die off gradually and the density of stands is decreasing. Therefore, these stands have to be transformed before losing their protective function. Original tree species (Norway spruce, beech) are planted in greater gaps of the stands. Another way is to remove every second row of trees. In these free rows original tree species are planted. Removal of blue spruce in rows is carried out by machine. Since the material cannot be used, it is chipped and remains in the stand. The remaining blue spruces are tended selectively.

Ten years after the beginning of conversion it is foreseeable that the individuals which were left will be overgrown by spruces and beeches planted between them. So they are likely to die off gradually. Therefore, presumably no measure is needed to remove them.

Scarification and liming of planting spots cause as a secondary effect the natural seeding of sallow (*Salix caprea* L.), European aspen (*Populus tremula* L.), European mountain ash (*Sorbus aucuparia* L.), and birch. Their litter is very important for the nutrient cycle. However, the natural seeding and also the underplanted trees are very attractive to game. Therefore, without fence, growth is put at risk.

Lodgepole pine is fast-growing and tolerant against air pollution and climatic conditions at higher altitudes. Its main disadvantages are susceptibility to snow breakage, damage by common pine sawfly (*Diprion pini* L.) and attraction to game. The selection of suitable provenance and the early strong tending of young stands are important for stability against breakage.

It is not urgent to transform stable stands. They should grow on and produce timber. Naturally seeded admixed tree species are supported by tending interventions.

Stands often damaged by snow breakage, common pine sawfly or red deer have to be transformed into mixed stands with original tree species in the same way as in the case of blue spruce. However, it is better to remove 2 or 3 rows next to each other instead of only one row. Lodgepole pine grows faster than blue spruce. Its branches fill the gaps between rows in a shorter time. The transformation is only advisable for stands up to the height of 5 m. In higher stands the remaining rows are not stable enough.

At present the conversion of **Serbian spruce** stands is not urgent, either. These stands need early tending to preserve their stability. The number of plants must be strongly reduced by young growth tending to get tall green crowns. Stable stands should be run as pure stands until tree stand age. Then, they should be underplanted with tree species of the natural vegetation. Serbian spruce stands are attractive to game. They are also damaged by honey fungus (*Armillariella mellea*).

The **larch species** have a special position. European larch was introduced to Saxony in the 18th century. The annual exchange of assimilation organs and the high regeneration capacity of the entire plant contribute to a relatively high resistance against air pollution. So, larch stands proved a success in the area damaged by air pollution.

In future the stand target type larch will be restricted to soils being dry or only moderately supplied with water and, furthermore, having only a low or medium state of nutrition. Cultivation will take place in small stands and without active introduction of admixed tree species.

In the long run, most of the existing pure larch stands of the same age will be transformed into mixed stands without larch. For this purpose the target tree species (beech, silver fir) will be introduced into the larch stand by underplanting. Larch is only temporarily present for one circulation period. Larch should only serve as shelter for the future tree species and must be held stable. Underplanting of admixed tree species should begin comparatively late and not before the larch stand has reached a top height of 20 m. Larch has a strong requirement for light and is also a fast-growing tree species. Larch crowns grow especially fast in their youth. The crown canopy is closed in a short time after thinning. Tree species which are underplanted suffer a shortage of light. Most of the larch stands are located at higher altitudes where light is one of the most important factors for growing. Prior to underplanting, the number of larches has to be reduced to approximately 400/ha. No more than 60% of the stand area should be underplanted. Suitable tree species in the higher mountain ranges are beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.). Admixed tree species should be planted only in groups of more than 1,000 square metres. Natural regeneration of broad-leaved tree species, spruce or pine should be integrated as far as possible.

Conversion of even-aged pure Norway spruce stands into mixed stands

In the lower and medium ranges of the Ore Mountains instable pure spruce stands are still prevailing. Prognoses of the regional climate predict an increase of the annual mean temperature (Enke, Küchler 2001). Hence, spruce is likely to reach its ecophysiological boundary in lower mountain ranges. Accordingly, the conversion of pure spruce stands is essential to restore stable ecosystems so that diverse ecological functions are met and lasting timber production is established. The silvicultural target consists in mixed stands with beech being the principal tree species. Depending on the state of nutrition and water supply, the following tree species will be admixed: silver fir (*Abies alba* Mill.), Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco), sycamore (*Acer pseudoplatanus* L.), ash (*Fraxinus excelsior* L.), wych elm (*Ulmus glabra* Mill.), at lower altitudes also oak (*Quercus*) species, small-leaved lime (*Tilia cordata* Mill.) and hornbeam (*Carpinus betulus* L.).

In general there are two ways of forest conversion:

1. the direct way of tree species exchange in connection with regeneration,
2. the indirect way by tending of stands.

Forest conversion by regeneration takes only a relatively short time interval. For this strategy a wide system of experimental plots has been built up on all typical sites of the Saxon lower mountain ranges since 1991. Investigations on the experimental plots cover the fields of yield survey, soil science and vegetation survey; they include biomass analyses of regeneration and ground layer.

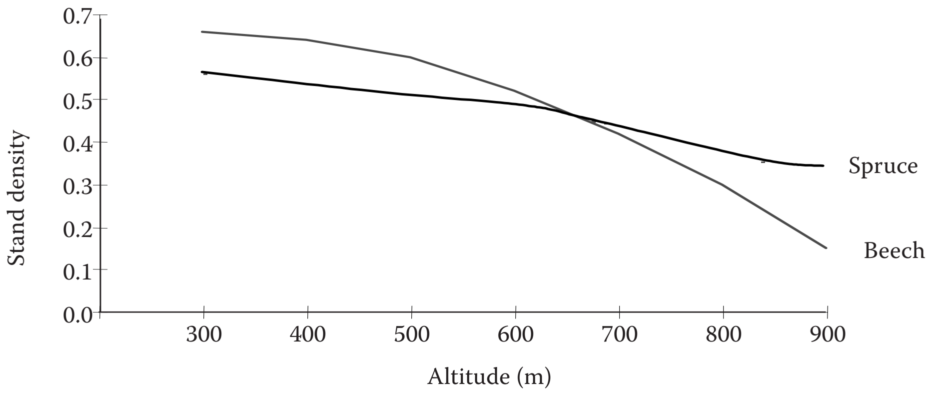

Fig. 1. Necessary lowering degree of density of the spruce upper stand related to altitude

On some experimental plots forest meteorological stations are installed to register environmental factors permanently and in relation to site, stand structure and management. Amongst others, included are irradiation, precipitation, soil moisture and temperature. Furthermore, ecophysiological investigations on assimilation and transpiration of upper stand, regeneration and ground layer are carried out. In particular the following questions are dealt with:

- Treatment of the upper stand (kind and intensity of opening-up),
- Tree species choice for regeneration,
- Mixture distribution,
- Soil preparation/liming,
- Method of planting/sowing.

RESULTS AND THEIR PRACTICAL IMPLEMENTATION

Light/temperature and opening-up of the upper stand

In mountains, temperature is an essential growth factor with increasing influence at a higher altitude. Therefore, forest conversion via regeneration depends very much on how far thermal and light requirements of the tree species are taken into consideration. The lowering degree of upper stand density is consequently an important means of regulation. Our investigations showed, for instance, a strongly increasing light requirement of beech regeneration from altitudes of 500 m above sea level. On the other hand, the light requirement of spruce rejuvenation is only slightly increasing. Thus, a spruce stand to be converted must be more opened up at higher altitudes than at lower ones (Fig. 1) (Irrgang et al. 1999).

For the underplanting of Douglas fir, a spruce stand at medium altitudes (450 to 700 m) should be opened up to a density degree of 0.2 to 0.3; at lower altitudes (300 to 500 m) a degree of 0.3 to 0.5 is advised. To secure a sufficient lateral protection, long regeneration areas should be preferred (Hering, Irrgang 2004). Silver fir requires a density degree of 0.5 to 0.7 for its smooth development. For oak species it may become necessary to clear the upper stand totally on small-scale places.

Water supply

Taking the results of regional climate models with the prospect of warming into consideration, on most Ore Mountains sites water will not presumably become limiting for growth due to its high starting level (Irrgang 2002). On the experimental sites water stress occurred only temporarily in markedly dry years as 2003 (Fig. 2).

Soil cultivation/liming

Soil preparation in connection with liming improves physical and chemical soil properties of the planting spot; at the same time competition of the ground layer is shortly reduced. Because of strong soil acidification in the Ore Mountains each planting action is connected with liming. Each planting spot or current meter, respectively, receives an amount of 0.5 to 1 kg Dolomitic limestone, which is taken in up to 40 cm.

If upper stand density and skeletal proportion are small, strip-wise soil cultivation (milling) in connection with thorough soil mixing has been proved favourable. To avoid root injuries to the upper stand, in stands with a stocking degree higher than 0.5 the cultivation work should be carried out spot-wise, by use of a small excavator or a planting-spot drill. The latter must be restricted to sites without tendency to waterlogging since, otherwise, in the planting holes stagnant moisture will develop. On waterlogged sites planting mounds built up by a small excavator are a proper solution.

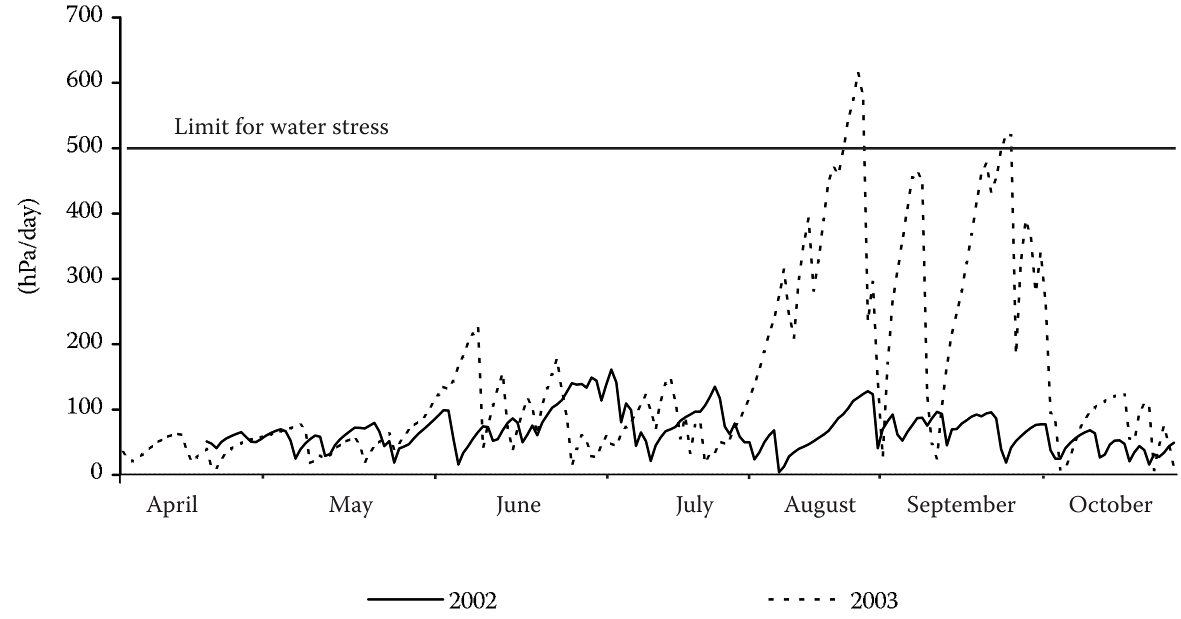

Fig. 2. Soil water suction in a pure spruce stand in the Ore Mountains (experimental plot Olbernhau) in 2002 and 2003

Choice of tree species and mixture distribution

In principle, several site-adequate tree species, if anyhow possible, should be included in the regeneration target to increase the ecological stability of the stand and to reduce the risk of damaging impacts. In this respect different site requirements of different tree species must be allowed for, and micro-site conditions are to be taken into consideration. Each tree species must be introduced into groups or nests. Mixtures of single trees were not favourable.

If possible, conversion should begin with shade-tolerant tree species as silver fir and beech. Depending on altitude, exposition and stand condition, regeneration places should have a size of 400 to 2,000 sq. m. The stocking degree will only be lowered above regeneration places. Sycamore, wych elm, ash and Douglas fir are suitable for the conversion of spruce stands. As a whole, no more than 60% of the stand should be regenerated. To stabilize the stand, intermediate lots with full stocking having a length of 20 to 40 m must be kept between the regeneration elements. Later on, these lots may be a basis for natural regeneration of spruce in medium mountain ranges.

Outlook

Forest conversion in the Ore Mountains aims at an ecosystem which, due to its tree distribution and structure, is able to respond elastically to forthcoming environmental changes and to regenerate its structure. The ecosystem must be highly resistant to extreme climatic events, to anthropogenic immissions and to biotic pests. The diversity of regeneration tree species should be further extended in relation to the site for the purpose of a better risk distribution. Particular attention must be paid to two research targets: suitability of foreign trees for cultivation and selection of temperature-tolerant as well as drought-resistant ecotypes of indigenous tree species. Best regeneration conditions are to be established by appropriate upper stand treatment and soil preparation. The final outcome of forest conversion should be a stable multifunctional forest ecosystem, diversified as to age and spatial structure, consisting of several site-adequate tree species. Essential for the success of forest conversion is the regulation of game density.

SUMMARY

The original natural forest ecosystems of the Ore Mountains (Norway spruce, silver fir and beech forests) have been destroyed by overcropping since the 11th century. In the 19th century spruce afforestations on large areas were intended to meet the steadily increasing demand for timber. They led to the introduction of planned forestry by building up spruce age-class forests. Efforts of a few forest specialists to establish an ecologically adapted silviculture failed before long due to economic necessities.

In the 20th century the large-scale pure spruce stands, most of which were not site-adequate, were strongly damaged by SO_2 immissions. These led by interaction with climatic factors within 30 years to

the breakdown of spruce stocks covering an area of 90 sq. km on the German side of the Ore Mountains, mainly in the higher mountain and ridge ranges. At medium and lower altitudes of the mountains, stocks were severely damaged.

Until the early 1990s no prospects for a clear reduction of immissions were foreseeable and, therefore, immission tolerant non-indigenous tree species were planted particularly in the higher mountain and ridge ranges in order to secure the vegetation type "forest". Damaged spruce stocks at medium and lower altitudes as well as in the less affected western part of the Ore Mountains were stabilized by intensive silvicultural treatment and liming.

By now SO_2 immission loads have strongly decreased. Accordingly, much better conditions have arisen to reverse site-inadequate substitute forests of non-indigenous tree species (blue spruce, lodgepole pine) in higher mountain and ridge ranges to spruce forest ecosystems. Here it is intended to establish in the long-run stable multifunctional forest ecosystems consisting of a mosaic of site-adequate tree species varying with the site and the climate of the Ore Mountains, which shows a slightly continental tendency. Beyond this, the active conversion of the large-scale pure spruce stands at medium and lower altitudes is highly important.

The paper presents the results of a complex experimental plot system aiming at the forest conversion in the Ore Mountains. Answers are given particularly to problems of the upper stand treatment for regeneration and of appropriate ways of soil preparation and planting. A network of forest climate stations and a broad variety of ecophysiological and yield investigations provide the basis for conclusions on light, temperature, soil and water demand by regenerated tree species.

References

ENKE W., KÜCHLER W., 2001. Klimaprognose für Sachsen – Regionalisierung von Klimamodell-Ergebnissen mittels des statistischen Verfahrens der Wetterlagen-Klassifikation und nachgeordneter multipler Regressionsanalyse für Sachsen Dresden. Unveröffentlichter Bericht.

HERING S., 1993. Waldbau im SO_2-Immissionsschadgebiet der sächsischen Mittelgebirge. Allgemeine Forstzeitschrift München, *48*: 1300–1303.

HERING S., 1999. Pflege und Umbau junger Bestände von Stechfichte, Murraykiefer, Omorikafichte und Lärchenarten. Allgemeine Forstzeitschrift/Der Wald Stuttgart, *54*: 1241–1247.

HERING S., IRRGANG S., 2004. Douglasienanbau in Sachsen – Empfehlungen zur waldbaulichen Behandlung. Merkblatt Landesforstpräsidium Graupa: 11.

IRRGANG S., 2002. Klimaänderung und Waldentwicklung in Sachsen – Auswirkungen auf die Forstwirtschaft. Forstarchiv, *73*: 137–148.

IRRGANG S., HERING S., EISENHAUER D.R., 1999. Waldumbau auf Tieflands- und Mittelgebirgsstandorten in Sachsen. Schriftenreihe der Sächsischen Landesanstalt für Forsten, Heft 19.

Received for publication June 6, 2005
Accepted after corrections June 24, 2005

Přeměny porostů náhradních dřevin a nesmíšených smrkových porostů v Krušných horách v Sasku

S. Hering, S. Irrgang

Landesforstpräsidium, Department of Silviculture, Central Forestry Department of Saxony, Graupa, Germany

ABSTRAKT: Původní přírodní lesní ekosystémy Krušných hor (smrkové, jedlové a bukové lesy) byly ničeny přetěžbami již od 11. století. V 19. století mělo zalesňování rozsáhlých ploch smrkem uspokojit stále rostoucí poptávku po dřevu. To vedlo k plánovitému hospodaření a ke vzniku lesů různých věkových tříd. Úsilí několika lesnických odborníků postavit lesnictví na ekologickém základě skončilo nezdarem vzhledem k ekonomickým potřebám dané doby. Práce uvádí výsledky šetření na komplexu pokusných ploch zaměřených na přeměnu porostů v Krušných horách. Řeší zvláště metody pěstování dospělých porostů zaměřené na jejich přirozenou obnovu, přiměřenou přípravu půdy a výsadbu. Síť lesních klimatologických stanic a velká různorodost ekofyziologických a výnosových výzkumných šetření poskytují základnu pro poznatky o potřebě světelných, tepelných, vlhkostních a půdních požadavků obnovovaných dřevin.

Klíčová slova: porosty náhradních dřevin; smrkové monokultury; přeměny druhové skladby; Krušné hory; Německo

Původní přírodní lesní ekosystémy Krušných hor (smrkové, jedlové a bukové lesy) byly ničeny přetěžbami již od 11. století. V 19. století mělo zalesňování rozsáhlých ploch smrkem uspokojit stále rostoucí poptávku po dřevu. To vedlo k plánovitému hospodaření a ke vzniku lesů různých věkových tříd. Úsilí několika lesnických odborníků postavit lesnictví na ekologickém základě skončilo nezdarem vzhledem k ekonomickým potřebám dané doby.

Ve 20. století pak byly četné smrkové monokultury (často nepřiměřené stanovištním podmínkám) silně poškozeny imisemi SO_2. Poškození v interakci s klimatickými faktory vedlo v průběhu 30 let ke zhroucení smrkových porostů na ploše 90 km^2 na německé straně Krušných hor (hlavně ve vyšších a hřebenových polohách). K silnému poškození došlo i v lesích ve středních a nižších polohách.

Až do počátku 90. let nebyla vyhlídka na snížení imisní zátěže, proto byly hlavně ve vyšších a hřebenových polohách vysazovány tolerantní nepůvodní dřeviny za účelem zajistit zde lesní porosty. Poškozené smrkové porosty ve středních a vyšších polohách Krušných hor byly stabilizovány intenzivními lesopěstebními metodami a vápněním.

V současnosti imisní zátěž prostředí silně poklesla a vznikly tak příznivější podmínky pro pěstování smrkových lesů i ve vyšších horských polohách na místě ekologicky nevhodných a nepůvodních náhradních dřevin (smrku pichlavého, borovice pokroucené). Je zde snaha o založení dlouhodobě stabilních polyfunkčních lesních ekosystémů, sestávajících z mozaiky ekologicky vhodných dřevin podle stanovištních a klimatických podmínek Krušných hor, které mají lehce kontinentální ráz.

Práce uvádí výsledky a závěry ze šetření na komplexu pokusných ploch zaměřených na přeměnu porostů v Krušných horách. Řeší zvláště metody pěstování dospělých porostů zaměřené na jejich přirozenou obnovu, přiměřenou přípravu půdy a výsadbu. Síť lesních klimatologických stanic a velká různorodost ekofyziologických a výnosových výzkumných šetření poskytují základnu pro poznatky o potřebě světelných, tepelných, vlhkostních a půdních požadavků obnovovaných dřevin.

Za nejnaléhavější jsou označeny přeměny porostů smrku pichlavého, a to nejlépe při výšce porostu pod 5 m. Je předpoklad, že cílové dřeviny (smrk ztepilý, buk) vysazené do kotlíků přerostou ponechané smrky pichlavé, které v zástinu uhynou a nebude nutné je odstraňovat. Méně naléhavé jsou přeměny porostů borovice pokroucené a smrku omoriky, u kterých se očekává produkce dřeva. Zvláštní pozici zaujímají porosty modřínu, považované za stabilizující a meliorační složku lesních ekosystémů zatížených znečištěním ovzduší. Podsadbami jedlí a bukem by měly být převáděny na porosty smíšené, kde by ponechaný podíl modřínu neměl klesnout pod 40 %.

Kromě toho je velmi významná i přeměna velkoplošných smrkových monokultur ve středních a nižších polohách. Pěstebním cílem jsou smíšené porosty s bukem jako hlavní dřevinou. V závislosti na stanovištních podmínkách by měly být přimíšeny jedle bělokorá, douglaska tisolistá, javor klen, jasan ztepilý a v nižších polohách duby, lípa srdčitá a habr obecný. Obecně doporučovanými pěstebními postupy při přeměnách jsou přeměny obnovou a výchovou.

Corresponding author:

Dr. Sabine Hering, Landesforstpräsidium, Central Forestry Department of Saxony, Department of Silviculture, Bonnewitzer Str. 34, D-01796 Pirna OT Graupa, Germany
tel.: + 49 (0) 3501 542 301, fax: + 49 (0) 3501 542 213, e-mail: Sabine.Hering@lfp.smul.sachsen.de