Multiple use forestry needs interdisciplinary research: report from a special research program on forest ecosystem restoration*

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Abstract
From 1997 to 2001 the Forestry Section at the BOKU University of Natural Resources and Applied Life Sciences in Vienna, Austria studied forest ecosystem restoration processes in an interdisciplinary research program. The need of forest restoration was noticed during the early 1980s, when researches emphasized that symptoms of forest decline can be considered as a mixed effect of both air pollution and historical changes in land use. We concentrated on secondary Norway spruce (*Picea abies* L. Karst.) stands on sites naturally dominated by broadleaves. Eleven discipline oriented working groups, ranging from eco-physiology, soil science, wild life ecology, and growth and yield, to socio-economics were linked. Some highlights of the results are presented to show the value of the integrated approach: The chain of blue stain fungi infection, decreased sap wood flow, release of volatiles of different mono-terpenes and bark beetle attraction was revealed. The dependence of shoot blight symptoms of Norway spruce, infected by *Sirococcus conigenus* on tree nutrition was clarified. The relationships between soil water conditions, transpiration behavior, rooting depth and growth of Norway spruce and beech in pure and mixed stands were explained. Through restoration processes the changes in forest regeneration, stand density and forage cover were modeled in order to describe their effect on roe deer habitat quality. Finally the way how these findings might find their way into forestry practices was studied and found to be most successful by personal communication.

Keywords: secondary forests, restoration, forest ecosystem, interdisciplinarity

1 Introduction

One of the results of the European debate on forest decline was that air pollution, nitrogen deposition (Katzensteiner *et al.* 1992) and climate change may affect forests directly as well as indirectly be increasing the occurrence of insects and diseases. As a result a “multiple stress hypothesis” focusing on stress scenarios and stress profiles of forest ecosystems (Führer 1994) was developed.

For centuries, Central European forests have been exposed to severe human impacts resulting in a significant reduction of forest covered land area, changes in forest distribution, and particularly changes in species composition and soil conditions (Glatzel 1991; Fanta

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1997). Fast growing tree species such as Norway spruce (*Picea abies* [L.] Karst) or Scots pine *(Pinus silvestris)* were grown in large areas beyond their natural range to increase commercial timber growth (GÜDE 1960). These secondary coniferous stands, mainly in areas below 1000 m elevation were found to be extremely sensitive to environmental stress factors and highly susceptible to progressive loading by air pollution and potential climate change (FÜHRER 1990), which was noticed as forest decline symptoms, i.e. needle losses and yellowing.

In forest decline literature many terms to describe forest health, stability, vigor, vitality are used, and most confusingly, some of these terms are used as synonyms, some of them are used with different meanings. Therefore a few definitions of some terms in the context of this study are in place.

Stability, in our context is the ability of stands to withstand adverse human or environmental impacts, while resilience is the ability to recover fast and without human intervention from diseases, and other disturbances. Forest ecosystem restoration we understood as all human interventions in secondary forests to improve stability, resilience and thus long-term sustainability including commercial efficiency, protection, environment and recreation. For further definitions in the context of forest restoration see HASENAUER (2004).

The development and implementation of strategies to repair such secondary forest ecosystems is an important challenge within forest ecosystem research (STERBA 1994; FANTA 1997). These ecosystems often suffer from severe temperature and water stress as well as biotic and/abiotic impacts. Stand stability and resilience to additional stress factors (e.g. air pollution, climate change etc.) may be extremely limited within these stands because the species may be not adapted to growing in pure stands on these sites, and severe decline in biodiversity (EMMER *et al.* 1998) may reduce the stands' resilience.

The Special Research Program (SRP) – *Restoration of Forest Ecosystem* launched in July 1997 addressed these issues. The mission of the SRP was to study and quantify processes of forest ecosystem restoration and evaluate the stability and resilience during the restoration phase. Twenty-three forest scientists at the BOKU University of Natural Resources and Applied Life Sciences in Vienna worked from 1997 to 2001 within the program. The program was jointly funded by the Austrian Science Foundation and the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (STERBA and HASENAUER 2000). After 2001 individual research projects have been funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management related to the same subject. Later similar research programs were launched in the Czech Republic ("secondary Norway spruce plantation"), and German research institutions ("Future oriented Forestry"). As a consequence to this common interests of many European countries, and a European-Overseas controversy on the necessity of forest restoration, the European Forest Institute (EFI) decided to establish and sponsor the **R**egional **P**roject **C**enter CONFOREST. Since 2001 eleven research institutions from nine European countries collaborate on the "Question of **Con**version of pure Secondary Norway spruce **Forests** on Sites naturally dominated by Broadleaves".

2 Objectives and focus of the Austrian special research program "forest ecosystem restoration"

Forest restoration as defined, has the aim to form stands that are more stable, and resilient, and thus able to fulfill human needs of commercial efficiency, protection, environment and recreation in a sustainable way. Mixed species stands comprising tree species well adapted to the specific site are supposed to be this aim. Thus, how the stands' condition finally should be is well known. Less known or even unknown are the effects of the interventions in the stands that should lead to these conditions. The processes following immediately after the interventions, as they may affect the ecosystem (e.g. soil properties, diversity of forest floor vegetation), the surrounding landscape (wild life habitat, runoff) and the socio-economic environment (role of hunting, income of forest owners, employment) need to be studied.

The restoration measures which we wanted to study were:

1) *Planting broadleaves and selective thinning in order to increase the proportion of broadleaves:* Secondary coniferous stands may suffer from significant lack in nutrition. Humus conditions, soil hydrology and soil biology, etc. are disturbed. Thus any way of increasing the proportion of broadleaves will induce soil processes, which may improve site conditions.
2) *Fertilization:* Nutrient input affects soil processes. However additional nutrients may have positive as well as negative side effects. For example, the positive impact is that susceptibility of stands for phloem feeders as well as fungi infections may be reduced (NEUMÜLLER 1994). Negative side effects are possible contamination of groundwater due to leaching and runoff (KATZENSTEINER *et al.* 1992).
3) *Thinning:* Generally it is assumed that decreasing stand density will increase tree vigor, stability, etc. of the remaining stand. The negative side effects may be decreasing stand stability (especially towards storm and snow breakage) immediately after treatment as well as higher run off rates etc.

Enhancing our understanding of forest restoration, the pertaining processes and the identification of risks during the different possible stand development phases after restoration are the main questions of interest. Since long term experiments on forest restoration are scarce and the processes involved depend very much on the natural and social environment (e.g. readiness to pay for restoration, perception of different forest types by different stake holders), our research program concentrated on certain sites as well as on a certain socio-economic environment.

Based on this, our research interests can be summarized as follows:

1) What stages are important during forest ecosystem restoration (i.e. the stage immediately after intervention, stand growth phases like thickets or pole stands one or two decades after the intervention, etc.)?
2) What risks may occur between the interventions and the finally achieved goal (e.g. snow breakage immediately after heavy thinning, release of nitrogen after fertilization, decrease of huntability for wildlife after large scale stand regeneration, etc.)?
3) How does fertilization affect the ecosystem compartments and their interrelationships?
4) What are the socio-economical implications (e.g. restoration costs, changes in commercial timber output due to changes in species composition, etc.)?
5) How do policy implications help in restoring forests (public funding strategies and implementation of research results within forest management plans)?

An important concern within our program was to approach forest ecosystem restoration in a quantitative way. This implies that the processes during restoration have to be integrated in models to study and evaluate possible restoration scenarios.

2.1 Study sites

The focus of the research program was on secondary Norway spruce (*Picea abies* [L.] Karst.) forests growing on sites naturally dominated by broadleaves. The region selected for our research program includes about 1 Million hectares, 25% of which are forested land. The proportion of (secondary) Norway spruce dominated forests is about 30 percent. The forest ownerships comprise all categories from owners of small woodlots to owners of larger forests, including the Austrian Federal Forests. Thus, the different attitudes towards forest restoration, as they may vary by the forest land owner category were covered very well in the research program.

The sites are located in elevations below 800 m a.s.l. Two growth districts, the Flysch-zone of eastern Austria and the adjacent zone of tertiary gravel were selected (Fig. 1). According to BERGER *et al.* (2002) the Flysch-zone is a narrow strip in the foothills of the Northern Limestone Alps. It consists mainly of old tertiary and Mesozoic sandstones and clayey marls. The soils are rich in nutrients with pseudogley dynamics. The natural forest vegetation of mixed species stands on Flysch is the Asperulo odoratae-Fagetum. The parent material of the tertiary sediments (gravel) consists mainly of quartz and siliceous material. Nutrient poor soils on semi-podzols and podzols are the dominant soil types. The natural forest vegetation is the Luzulo nemorosae-Fagetum.

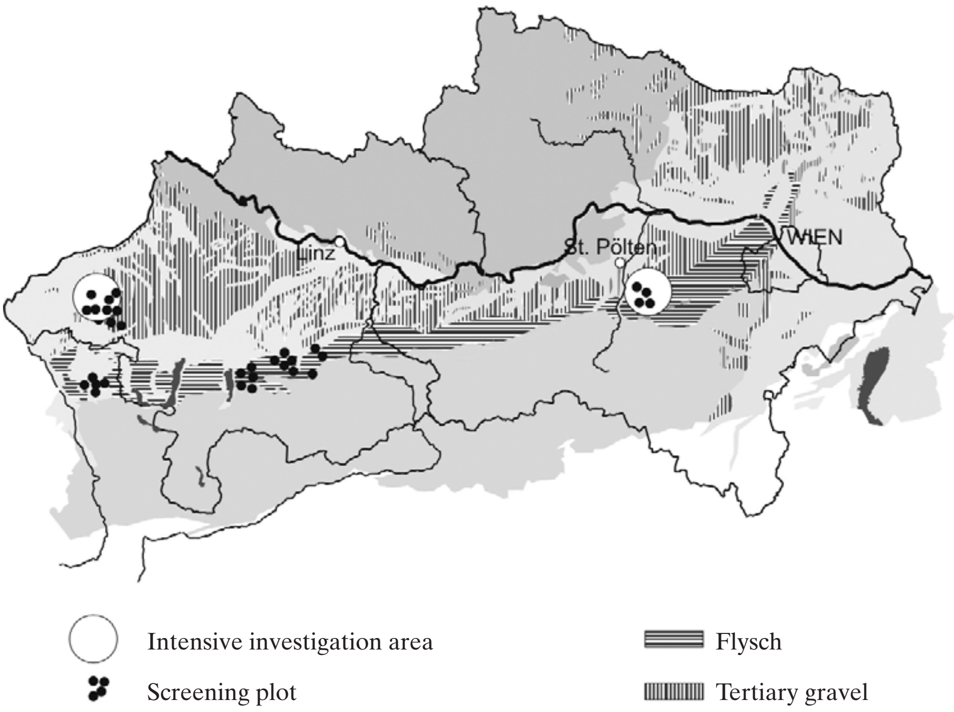

Fig. 1. The location of the plots of the special research program Forest Ecosystem Restoration.

3 The overall methods concept

Since our objective was to study the interactions between the different compartments of the ecosystem and the socio-economic environment, i.e. the interfaces between (i) soil and trees or stands respectively, (ii) climate, soil and forest stands, (iii) phloem feeders, fungi, their pathogens on one side and the host trees on the other, (iv) wildlife and forests and (v) stakeholders and forests, we chose a twofold methodology to investigate the results of restoration dynamically. (1) Discipline oriented groups that dealt with special processes, and (2) joint activities to ensure the interfaces and cross-disciplinary understanding, i.e. joint work at the same objects (trees, plots, stands), joint seminars, meetings, etc.

3.1 The discipline oriented project research groups

The research groups focused on:

1) Soil science – dealing with carbon and nutrient cycles. Especially nitrogen in the ecosystem was expected to be managed through species composition, thinning and fertilization.
2) Ecophysiology – studying tree water condition, i.e. sap flow and water stress.
3) Hydrology and climatology – investigating the effect of tree species composition on stand climate, soil water balance and runoff.
4) Growth modeling – dealing with the effect of restoration measures on tree growth, in order to make tree growth models suitable to deal with the effects of changing species composition and soil parameters and their feed back loops.
5) Regeneration and genetics – dealing with the potential for natural regeneration and the influence of restoration measures on the allelic and genotypic structure of the tree populations.
6) Forest entomology – studying the susceptibility of trees for phloem feeders, with special emphasis on the relationships between pathogen, and host-tree. Special attention was paid to the role of blue stain fungi of the genera *Ophiostoma* and *Ceratocystis*, being associated with bark beetles.
7) Phytopathology – dealing with the susceptibility of Norway spruce to twig fungi, in particular the relationships between *Sirococcus conigenus, Pezicula livida* and *Macrophoma* sp. and their interaction with the nutritional status and the stress levels of host trees.
8) Stability and silviculture – working on the resistance of different stand types against wind throw by studying coarse root distribution of Norway spruce and beech in different mixtures.
9) Wildlife ecology – dealing with the habitat quality of different forest types for roe deer and the susceptibility of stands to browsing.
10) Socio-economics – studied the awareness of forest owners and managers concerning the risks of pure Norway spruce forest management, and discussed costs and benefits from forest ecosystem restoration.
11) Policy analysis – investigated the ways how scientific knowledge on forest restoration and its necessity is adopted by forest practitioners, owners and forest authorities.

3.2 Interdisciplinarity and collaboration within the program

The interdisciplinarity of the program was achieved by (i) concentrating the work of the groups, which worked on the tree level and on the stand level in the same stands, and plots (Fig. 1) and (ii) regular workshops, where all groups reported on their findings and discussed them. In this way the "natural science groups" were linked with the "socio-economic" and the "policy analysis group". During the workshops new hypotheses were created, discussed and then were tested by the respective group, having the appropriate method at hand.

3.3 The concept of screening and intensive research plots

On the one hand it is almost impossible to experimentally disturb ecosystems and wait until they have recovered, thus we modified ASSMANN'S (1961) growth series concept, the idea of which is to replace the long term observations (up to rotation length) of one plot, by the short-term observation of stands of different ages. On the other hand short and long-term effects may not be the same, and information is needed on different time scales, Therefore we installed a system of

1) screening plots, and
2) plots for intensive research.

The basic idea of our screening plots was to explore the development of stands after the application of restoration measures. During the screening procedure, plots of 300 to 750 m^2 size, containing a minimum number of 30 trees, were established in different types of stands, ranging from the expected worst case (poor secondary spruce stands) to the hypothesized optimum case (fully restored stands). Thus, our screening plots concentrated on short-term observation of pairs of stands, one selected to represent pure Norway spruce stands before any restoration measure, and the other one, selected as a "restored" stand, having a more appropriate species mixture, or being thinned or fertilized. The screening of these 32 pairs of stands (Fig. 1) served to (i) describe and interpret differences between "unrestored" and "restored" stands, to (ii) create hypotheses on the restoration process, which later on should be tested in experiments, and (iii) to select two main intensive investigation areas, where the primary site factors were most comparable, and where the differences were most reasonably attributed to differences in management, thus restoration. On each of the screening plots, a detailed site description, soil analyses, comprising a multitude of physical and chemical soil parameters, vegetation analyses, and measurements to calculate stand characteristics (site index, different measures of stand density, dbh-distribution, species proportion, increment, etc.) were performed. Based on these results we selected a limited number of permanent research plots of about 0.5 to 1.0 ha size, for long-term observation. Data from these plots will allow us to shift systematically from a false time series concept (ASSMANN 1961) to time series analysis of forest ecosystem restoration covering different stand development stages after restoration, as they are observable on given sites.

While in the intensive research plot on tertiary gravel, mainly regeneration was studied, in the one in the Flysch-zone soil water dynamics were studied by direct measurements of precipitation and interception, and soil water storage on 200 measurement locations per stand (pure beech, pure spruce and mixed spruce-beech) over half a hectare each. Sap flow was measured on individual trees and scaled to the stand level by leaf area estimates. Canopy conductance was calculated from stand transpiration and meteorological data. The vertical distribution of coarse roots and fine roots was evaluated in 10 soil pits per stand and tree growth was assessed from cores of 30 trees per stand.

For more details of the methodological concept as well as of first results we refer to HASENAUER and STERBA (1999, 2000), and STERBA and HASENAUER (2000), respectively.

4 Results

The four year program with eleven project parts delivered information published in more than 60 contributions in refereed international journals and in more than 60 contributions to congress and conference proceedings.

Following we present some highlights of the interdisciplinary results to show the value of the integrated approach. Except the first example, the following ones all are the result of the collaboration of several project groups, and could not have been achieved by one single group (Fig. 2).

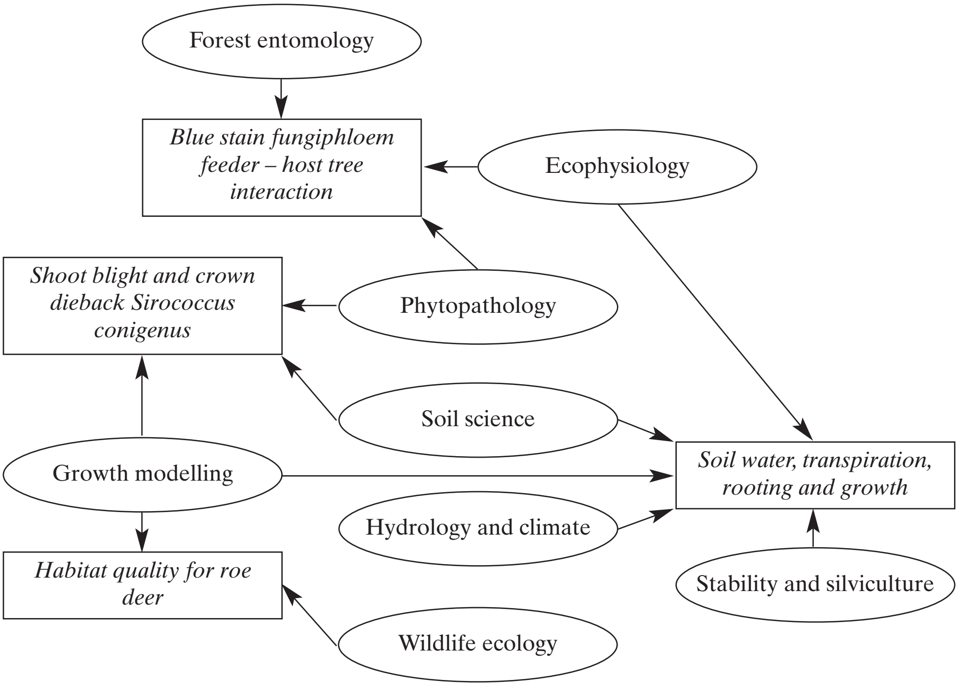

Fig. 2. The collaboration of the discipline oriented project groups to achieve the sample results.

4.1 Socio-economics interacting with natural sciences

Studying old maps, documents, and aerial photographs revealed that historically there was not at all a general trend towards Norway spruce plantations. Again and again, since the 17th century, there had been reports and warnings of increased susceptibility of such stands to abiotic (wind, storm, snow) and biotic (bark beetles) damages. Depending on the type of ownership, restoration measures, especially conversion to broadleaf stands, have already been taken in the past.

The hypothesis that political measures and processes follow “perception not facts” (PREGERNIG 2000) was supported by the evaluation of a questionnaire. This means, if humans perceive situations as real, they are real in their consequences (PREGERNIG 2002). The joint workshops with the natural science working groups revealed that this hypothesis was also valid for the scientists themselves.

The study of how scientific knowledge was incorporated into forestry practices showed that neither scientific nor professional literature, but rather personal communications with scientists and colleagues (peer group orientation) in informal contacts were the main way that practitioners accepted knowledge and put it into practice. Information from colleagues in other forest enterprises was perceived as more trustworthy information from published sources or seminars.

4.2 Interaction between blue stain fungi, phloem feeders and host trees

Blue stain fungi *(Ceratocystis polonica)* are suspected to help their vectors (phloem feeders, i.e. *Ips typographus, Pityogenes chalcographus*) to overcome the protection system of their hosts (Spruce). After inoculation with blue stain fungi, Norway spruce host trees built occlusions in the sapwood (KIRISITS and OFFENTHALER 2001). Experiments with sapflow interruption led to changes in the pattern and concentration of mono-terpenes. The mono-terpen patterns within the bark of different spruce clones varied only minor within the clones, but differed considerably between the clones. While the mono-terpene patterns did not vary within the clones, the concentration of mono-terpernes as a whole varied considerably as well within as between the clones. The mass inoculation of the bark with *Ceratocystis polonica* resulted in a dramatic rise in mono-terpene concentration, and significantly different mono-terpene patterns, which enhances the defence mechanism of spruce through the release of resin flow and may also enhance bark beetle attraction (BAYER *et al.* 2002).

4.3 Shoot blight and crown dieback of Norway spruce through *Sirococcus conigenus*

In the pure Norway spruce stands on the tertiary gravel, severe shoot blight and crown dieback was found. Isolations from the shoots of affected branches of mature trees confirmed that *Sirococcus conigenus* is a major cause for this shoot blight and dieback. In an old fertilization experiment, unfortunately lacking an appropriate statistical design (no replications, only one treated and one untreated plot), the severity of the symptoms was significantly lower in the fertilized plot, indicating that nutritional imbalances may be an essential factor for the development of the symptoms. Significantly smaller growth rates in trees with *Sirococcus* symptoms were found in both, young and old stands (HALMSCHLAGER *et al.* 2000). The pathogenicity and infection biology of *S. conigenus* was evaluated in inoculation experiments. It was possible to produce the same symptoms as found in natural stands. Although the proportion of diseased trees was low in the whole experiment, the highest proportion was found in artificially inoculated seedlings enclosed in plastic bags or incubated in growth chambers under saturated moisture conditions. Differences of incidence of shoot blight between a control variant and two Mg-fertilizer variants showed that Magnesium deficiency increases the expression of *Sirococcus* symptoms (ANGLBERGER and

HALMSCHLAGER 2000). An individual tree fertilization experiment with a statistically sound design, in a mature stand on a tertiary gravel site with extremely poor Mg-nutrition is going on and seems to support the hypothesis on the relationships between Mg-nutrition, *Sirococcus* symptoms and tree growth. If this is true, Magnesium fertilization could improve the resistance of pure Norway spruce forests to shoot blight.

4.4 Relationships between soil water conditions, transpiration, rooting and growth of Norway spruce and beech in pure and mixed stands

In the intensive research plot in the Flysch-zone, the transpiration measurement exhibited that beech trees consumed about five times the water of equally sized spruce trees (HIETZ *et al.* 2000). On the stand level, the transpiration of the mixed stand exceeded that of the spruce stand by 50% in the vegetation period 2000. Thus, the mixed stand extracted 45% more water from the upmost 60 cm of the soil than the spruce stand. The mixed stand partially compensated its higher extraction rates by a more efficient rewetting, its interception was only 60% of that of the spruce stand (GLATZEL *et al.* 2000). Fine root biomass in the mixed stand exceeded the one in the pure spruce stand, whereas coarser root biomass did not differ between the stand types. All pure stands concentrated their coarse root biomass in the upper 40 cm soil depth. This concentration was more pronounced for spruce than for beech. In the mixed stands of spruce and beech, the roots were distributed shallower than in the pure stands. Furthermore the spruce roots were less abundant in the mixed stands than in the pure stands (SCHMID and KAZDA 2001, 2002). This may explain the better growth of smaller spruce trees in the mixed stands, compared with equally sized spruce trees in the pure spruce stand (STERBA *et al.* 2002), and, maybe the enhanced individual susceptibility of small spruce trees to wind throw in the mixed stands. These growth relationships could be generalised in the Austrian individual tree growth model PROGNAUS (MONSERUD and STERBA 1996), based on the data of the national forest inventory, which had to be improved by an interaction term for species mixture and competition (VOSPERNIK and STERBA 2001).

4.5 Change of habitat quality for roe deer through restoration processes

In a 600 ha management district, after a storm event, many stands were totally blown down. The age structure thus was changed and the species composition of the naturally reforested stands was changed in a way which may be regarded as a conversion from pure Norway spruce management towards a more nature oriented management with very high proportions of broadleaves. Twelve years observations on habitat quality, visibility and huntability of roe deer, and browsing included fenced and unfenced areas. Habitat quality observation showed that the thermal cover (protection from climatic extremes through the canopy) increased, while the hiding cover and the food availability decreased. The visibility and the huntability of roe deer decreased, because suitable areas for roe deer observation by hunters decreased and selective culling became more difficult. The observations were further used to validate an earlier developed expert system (REIMOSER 1994; PARTL 2001) predicting the predisposition of forests towards game damage. The browsing impact on forest regeneration indeed was higher in places where increasing predisposition was predicted. The development of regeneration and vegetation, providing forage for roe deer appeared to be an important factor, which needs to be predicted if the short- and long term consequences of restoration measures for wild life habitat quality are to be evaluated. BOKALO (2001) used the data of the Austrian National Forest Inventory, to enhance the individual tree growth simulator PROGNAUS by implementing equations to predict the probability of regeneration and forage cover, depending on stand treatment and restoration measures.

5 Conclusions

The collaboration between the working groups, and the research approach to combine short-term observations of many plots with intensive observations in a few long-term research plots proved to be successful already after a few years. The collaboration between the groups, dedicated to "natural science" helped to reveal many interactions, thus creating a better understanding of ecosystem reactions to restoration measures. The main contribution of the socio-economic, and the forest policy group was to proof that the stakeholders' attitude towards forest restoration is more a question of perceptions and values, than a straight forward result of the findings of natural science. Thus the incorporation of scientific knowledge into forestry practices still is a challenge, needing continued efforts from both, natural sciences and social sciences.

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