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DEVELOPMENT OF FOREST REGENERATION IN BAVARIA AFTER THE STORM DAMAGES IN 1990

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Abstract

After the serious storm damages in 1990 the Bavarian State Institute of Forestry set up more than 60 sample areas at 12 different locations in Bavaria in order to investigate forest regeneration. Several sample areas were provided for natural regeneration, others were planted or seeded. The lecture describes the impacts on tree survival during the first years at the level of single trees and the impacts on tree density development at the stand level until 2000. It focus on the question, whether, retrospective judging, we could have act differently when considering the information provided shortly after the storm damages. At the level of single trees it was determined that mainly planting mistakes with the consequence of drought damages, game browsing, but also competitive vegetation and soil damages affected the survival of the trees within the first years. But these impacts at the level of single trees showed not much impact on the development of the tree density at the stand level. The most sample areas with artificial regeneration were covered very densely already in 1992 so that the losses due to competition started at once. Apparently lesser densities of planted trees would have been sufficient. The amount of additional natural regeneration of coniferous trees during the first years couldn't have been foreseen. Only a very high tree density at the beginning ensures few additional natural regeneration of spruce or pine. At least soil damages should be avoided, if additional natural regeneration of coniferous and broad-leafed pioneer tree species are not desired. The development of the sample areas provided for natural regeneration show that a conversion towards deciduous forests doesn't take place within a short time, if there is not much regeneration of broad-leafed terminal tree species at the beginning. If a quick conversion towards broad-leafed terminal tree species is desired, artificial regeneration is necessary.

1 Introduction

Two gales caused serious damages in Central European forests in 1990. More than 5% of the area of the Bavarian state forest was damaged at that time (König et al 1995). After these damages the Bavarian State Institute of Forestry set up more than 60 sample areas at 12 different locations in Bavaria in order to investigate forest regeneration. First results from this investigation were reported by Fischer and Mößmer 1999. Several sample areas were provided for natural regeneration, others were planted or seeded. Timber was removed from some of the areas provided for natural regeneration, others were left completely untouched. Thus there are pairs of areas with timber removed and not removed, both with natural regeneration at the same locations and pairs of areas with natural and artificial regeneration at the same locations. A lot of data was collected from the sample areas in 1991/92, 1995 and 2000, among other data the number of plants of different tree species, tree height and diameter, damages, the amount of remained timber and slash, the length and depth of machine tracks, characteristics of the former stand and of the site. At the sample areas with natural regeneration the vegetation development was recorded by the Institute of Geobotany of the Technical University of Munich (see lecture Fischer & Märkl).

This lecture will focus on the question, whether, retrospective judging, we could have act differently when considering the information provided shortly after the storm damages. Can we find patterns of forest regeneration so that we can make silvicultural measures more efficient in case of future damages? Here will be presented only a choice of results.

Fig. 1 shows the tree density at the sample areas provided for natural regeneration in 1992 and in 2000 in the same order. The composition of terminal tree species is dominated by coniferous tree species, mainly spruce, as the former stands were mostly, too. When comparing the tree densities 10 years after the storm damages with standard tree densities recommended for plantations, it is to state that several sample areas are not completely covered with a new forest stand. On the other hand there are sample areas with sufficient regeneration of terminal tree species in 2000 although there were loose regeneration a short time after the damages. Could we have foreseen the amount of additional natural regeneration with the information available in 1992?

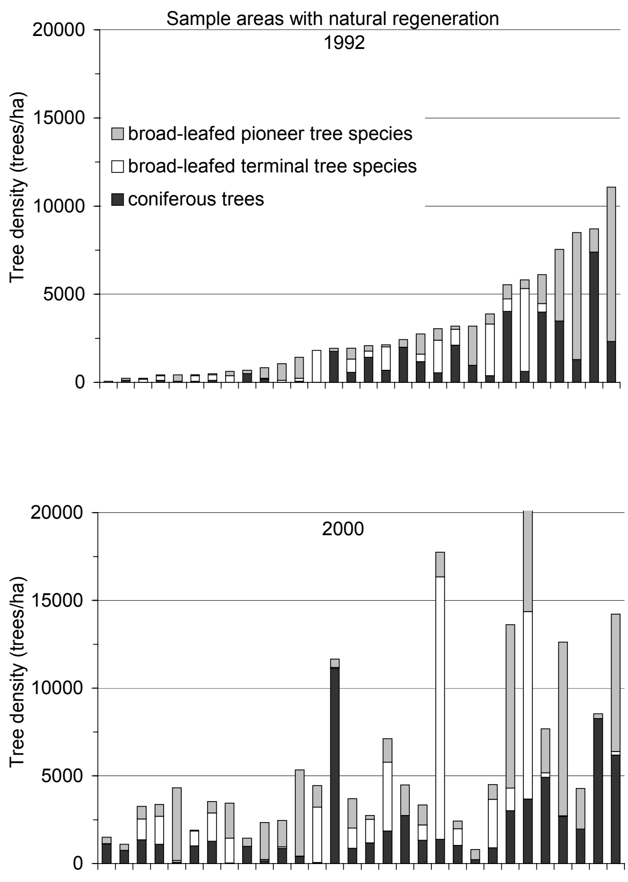

Fig 1 a, b: The tree density at sample areas with natural regeneration.

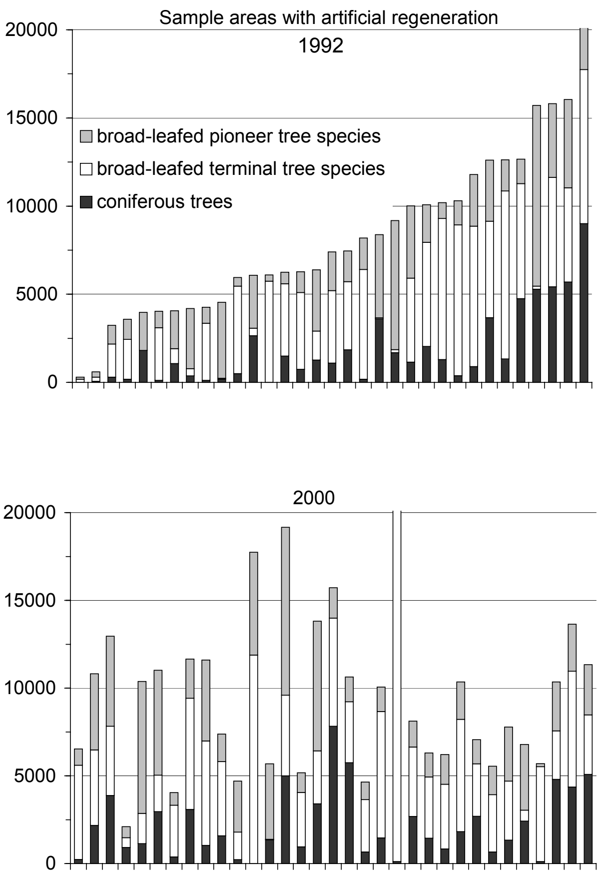

Fig 2 a, b: The tree density at sample areas with artificial regeneration.

Fig. 2 shows the tree density at the sample areas provided for artificial regeneration. Mainly broad-leafed terminal tree species like European oak, sycamore maple, ash and beech were planted. Pioneer tree species, mainly birch, rowan berry, willow and poplar stem from natural regeneration. Poplar was planted only at few sample areas as a shelter for terminal tree species, which were planted a few years later. All coniferous trees, mainly spruce, stem from natural regeneration. Comparing with standard tree densities we see that the most sample areas where completely covered with regeneration already 1992. Maybe that artificial regeneration to a lesser extent would have been sufficient. In 2000 only one area wasn't covered completely. The area covered by coniferous trees alone in 2000 at some sample areas suffice for a complete regeneration. Could we have foreseen this amount of natural regeneration of coniferous trees?

Data were collected from single trees along the diagonals of the sample plots. Furthermore we have data regarding the whole sample plots. Thus, at first the development during the first years at the level of single trees will be investigated. Afterwards we will look at the development at the forest stand level.

2 Development of single trees until 1995

There were data collected from 3000 trees in 1992. About 18% of the plants were droughty at the top. In part even the entire sprout was droughty (see tab. 1). Planted trees were droughty much more frequently than plants from natural regeneration. The risk of a drought damage of planted trees was about 85% greater (92.3%-7.7%).

Tab.:1

	Natural regeneration	Planted trees	Sum
Top not droughty	1072 43.9%	1369 56.1%	2441 82.1%
Top droughty	41 7.7%	492 92.3%	533 17.9%
Sum	1113	1861	2974

The odds ratio of the frequencies shows the chance of a drought damage in case of planting proportional to the chance in case of natural regeneration.

$$\mathrm{OR} = \frac{1072 \cdot 492}{41 \cdot 1369} = 9{,}40$$

Thus the risk of a drought damage was in case of planting nearly tenfold in comparison to that of natural regeneration. Besides planting the amount of slash showed a relation to drought damages, too. The height and cover degree of slash was estimated in a radius of 50 cm around the single trees. Let us take 0.1 m³ slash in the 50 cm radius as a value of threshold. The odds ratio increases for trees beyond this threshold, that is with much slash in the surrounding, to 27. A logistic regression with the explanatory variables “planting/natural regeneration” and “much/less slash” and the dependent variable “with/without drought damage” results in adjusted odds ratios for the planting effect of 10.3 and for the slash effect of 2.0. Thus the risk of drought damages was in case of planting much higher than in case of natural regeneration and it was doubled by a large quantity of slash. Presumably drought damages are the consequence of inappropriate planting methods (see lecture Nörr). The impact of slash can be explained that way that lots of slash hampers planting and makes mistakes more frequent. The regression coefficients of both explanatory variables are significant at the 1%-level.

In 1995 1.6% of the plants registered in 1992 were dead and 21% couldn’t be found again. We assume that most of the disappeared trees were dead, too. By means of logistic regression we analyzed, which factors existing in 1992 can explain the death or disappearance of the trees. Thereby the trees, which were already dead in 1992 (2%) were excluded. The criteria “planting/natural regeneration”, “drought damages” and “browsing damages by game” showed a significant impact on the death or disappearance of the trees. It is plausible that drought damages and browsing reduced the chance of survival. Implausible is that planting increased the chance of survival. Maybe that planted trees have been found easier because of the regular formation. Thus, in the following only the collective of planted trees was analyzed. Because in case of this trees payments were necessary, the survival of this trees is interesting. The following variables showed a significant impact on the death or disappearance of the planted trees:

- with/without drought damages
- with/without browsing damages by game
- with/without competitive vegetation in the radius of 50 cm
- with/without soil damages in the radius of 50 cm

The risk of a loss was in case of drought damages (odds ratio=2.3) and game browsing (odds ratio=2.3) more than doubled. Competitive vegetation (odds ratio=1.4) and soil damages (odds ratio=1.4) increased the risk about one third. An effect of the slash couldn't be proved. A possible interaction of the parameters couldn't be proved either.

Thus we can conclude that mainly planting mistakes with the consequence of drought damages, game browsing, but also competitive vegetation and soil damages affected the survival of the trees within the first years.

3 The development of tree density

Fig. 1 and 2 show that the tree density at the sample areas differed between areas provided for natural and artificial regeneration. Therefore their development will be described separately.

3.1.1 The development of tree density at sample areas with artificial regeneration until 1995

The parameters affecting the change of tree density between 1992 and 1995 were searched by means of multiple regression analyses. The following parameters came into consideration:

- the altitude
- mainly planted tree species (nominal scale)
- tree density in 1992 (trees per ha)
- cover degree of the herb layer (%)
- volume of remained timber (m^3/ha)
- amount of slash (m^3/m^2)
- age of the former stand
- distance to the next old stand (m)
- soil moisture (ordinal scale from dry to wet)
- length of machine tracks (m)
- frequency of soil damages (proportion of trees with soil damages in the 50 cm radius)
- browsing damage by game (proportion of damaged trees)
- drought damages (proportion of damaged trees)

The tree density increased on average at sample areas with artificial regeneration by 430 trees/ha with a maximum increase of 18600, a maximum decrease of 8000 and a standard deviation of 4600 trees per ha. We found that the development of tree density can be described better, if we separate between the different groups. The difference of the density of **broad-leafed terminal tree species** between 1992 and 1995 can be explained by

- tree density 1992 (-)
- cover degree of herb layer (-)

This model can explain 30% of the variation (R^2=0.31). The regression coefficients are both highly significant. The density decreased at average about 1500 trees per ha with a standard deviation of 1900. The signs of the coefficients (in brackets) are both plausible. The negative sign of the "cover degree" shows that the competition of the herb plants is still going on. The negative sign of "tree density 1992" indicates that the losses due to competition between plants has already started.

The density of the **coniferous tree species** increased until 1995 by 500 trees per ha (mean) with a great variance. The differences can be explained by

- the altitude	(-)
- the length of machine tracks	(+)
- tree density 1992	(quadratic)

The regression coefficients are all significant at the 1%-level, but the model can explain 30% of the variation only. High altitudes are unfavorable for tree growth, thus more losses or few increases are plausible. The germination of spruce can be improved when the mulch layer is raked by machines. At sample areas with low tree densities in 1992 the quantity of coniferous trees increased. At densities around 8000 trees/ha in 1992 the maximum increase of coniferous trees could be found, whereas more often losses of coniferous trees were recorded in case of higher tree densities in 1992. Because the coefficient of determination is very low, we can conclude that it was not possible to foresee the amount of natural regeneration of coniferous trees in 1992. Only afforestations with tree densities beyond about 10000 trees per ha can avoid further natural regeneration of coniferous trees. But such tree densities can not be recommended, because they are very expensive. Soil damages by machine tracks should be avoided, if natural regeneration of spruce and pine is not desired.

The density of **broad-leafed pioneer trees** increased between 1992 and 1995 about 200 trees per ha with a great standard deviation of 2300 trees. The difference between 1992 and 1995 can't be explained satisfactorily. Only the distance to the next old stand has a significant relation to the difference of pioneer tree densities. It is a logarithmic relation with a negative sign. Beyond distances of 100 m we never found much additional natural regeneration of broad-leafed pioneer tree species.

3.1.2 The development of tree density at sample areas with artificial regeneration between 1995 and 2000

Between 1995 and 2000 the density of **broad-leafed terminal tree species** decreased about 1200 trees/ha further with a standard deviation of 1800. This development can be explained by the

- altitude	(+)
- mainly planted tree species	
- tending	(+)
- tree density in 1995	(-)
- soil moisture	(-)
- frequency of soil damages	(quadratic)

This model can describe about 80% of the variation of the density development (R^2=0.79). At sample areas where particular trees species were planted very densely, e.g. oak, the density decreased rapidly until 2000. Tending is an additional parameter, because between 1995 and 2000 some sample areas were tended. The positive sign of tending means that tending was effective. The broad-leafed terminal tree species are the target species at the sample areas. In case of tending the decrease of this species has been decelerated. The quadratic relation of soil damages to the density development means that together with increasing soil damages the density of broad-leafed terminal tree species increased or decreased slower until a maximum. When soil damages increased further, tree density of this species decreased more and more.

Until 2000 the density of **coniferous trees** decreased about 500 trees/ha at average with a standard deviation of 2000. Only about 30% of the variation (R^2=0.29) could be explained by the following variables:

- mainly plated tree species
- tending (-)
- crown cover (-)

Instead of the tree density in 1995 the crown cover proved to be a more suitable explanatory variable. The crown cover was calculated according to Biber 2002. From the tree density which is possible at maximum the space demand of the tree crowns depending on their height was calculated. The sum of the space demand of all trees is the crown cover of the sample area. A large crown cover causes much competition between the trees. Thus the negative sign is plausible. The crown cover alone can explain more than 20% of the variation. Apparently coniferous trees were cut, too, when the stands were tended.

The **broad-leafed pioneer tree species** decreased at average about 170 trees/ha between 1995 and 2000 with a standard deviation of 1800. The following parameters can explain 60% of the variation of the density development:

- mainly planted tree species
- amount of slash in 1995 (-)
- soil moisture (-)
- crown cover (-)

All variables are significant at the 1%-level. It may be surprising that tending is not listed here, because pioneer tree species are mainly cut when tending. But if the variable "crown cover" is excluded the parameter "tending" gets significant. The crown cover is dominated by pioneer tree species and sample areas with a large crown cover have been tended prior, apparently.

3.2 The development of tree density at sample areas with natural regeneration

The development of sample areas where the timber has been removed differed from those where the timber wasn't removed so they have to be treat separately.

3.2.1.1The development at sample areas where the timber wasn't removed until 1995

About 1700 **broad-leafed terminal trees** per ha were found at these sample areas at average in 1992 only. The tree number decreased until 1995 at average about 100 trees/ha with a standard deviation of 1800. Only the tree density in 1992 had a significant relation to the development of broad-leafed terminal trees species density until 1995. But this variable can explain the variation to a very small degree. The number of **coniferous trees** at the beginning was low either (870 trees/ha average). It increased until 1995 about 600 trees/ha with a large standard deviation of 3500. We couldn't found an appropriate model for describing the density development of these species. **Broad-leafed pioneer tree species** had a density of average 1100 trees/ha at the beginning and increased until 1995 about 500 trees/ha with a standard deviation of 2500. Half of the variation of the density development until 1995 can be explained by the tree density in 1992 (R^2=0.52). The sign of the coefficient is negative. Together with an increasing tree density in 1992 the density of the pioneers increased slower or decreased faster until 1995.

3.2.1.2 The development at sample areas where the timber wasn't removed from 1995 to 2000

The density of **broad-leafed terminal trees** now increased at average about 600 trees/ha with a standard deviation of 1500. The following factors had a significant impact on that development:

- amount of slash in 1995 (-)
- browsing damage by game (-)

Both variables can explain 30% of the variation only, not enough for a reliable forecast. In contrast the further development of **coniferous tree species** density could be explained with great accuracy (R^2=0.86) by the following significant factors:

- altitude (+)
- soil moisture (+)
- browsing damage (-)
- tree density in 1995 (+)

The tree density in 1995 alone can explain 75% of the variation. The tree density of coniferous trees increased at nearly all sample areas, at average about 1000 trees/ha. The standard deviation was 1200. Great density increments where related with high tree densities in 1995. If there was a loose tree density in 1995 scarcely further natural regeneration of coniferous trees could be found. Thus we couldn't have expected much further natural regeneration of spruce or pine in 1995 at sample areas with remained timber and a loose tree density at that time.

The density of **broad-leafed pioneer tree species** increased until 1995, too, at average about 1000 trees/ha with a standard deviation of 1900. Only the distance to the next old stand showed a significant impact on this development. There is a quadratic relation. If the next old stand was close, the density of pioneers increased scarcely. If the distance was greater, frequently the density increased much. In case of large distances the number of pioneers increased again only little or even decreased. This relation is plausible. If the next old stand is very close, there is shadow of the neighboring old stand in addition to the shadow of the remained timber by what the establishment of pioneer tree species is hampered. In case of very large distances there is not much carry-over of seeds. But the coefficient of determination is very low (R^2=0.27).

3.2.2.1 The development at sample areas where the timber was removed until 1995

There were 600 trees/ha of **broad-leafed terminal tree species** at average in 1992 and 1300 trees/ha of **coniferous species**. Both increased slightly until 1995, at average about 300 resp. 400 trees/ha with a large standard deviation at each case. We couldn't found an appropriate model for explaining the development.

There were at average 1500 trees/ha of **broad-leafed pioneer species**. The density of these species increased about 2000 trees/ha with a large standard deviation of 4300. The following variables had a significant impact on this development:

- tree density in 1992 (+)
- frequency of soil damages (+)
- soil moisture (+)

Large increments of pioneer tree density were found mainly at areas, which were covered already rather dense in 1992. Soil damages improved the natural regeneration of pioneer species. A model consisting of these three variables can explain the variation of density development only to a small extent (R^2=0.27).

3.2.2.2 The development at sample areas where the timber was removed from 1995 to 2000

The number of **broad-leafed terminal tree species** increased until 2000 again very slightly (+300 trees/ha). Again we couldn't found an appropriate model for explaining this development. The density of **coniferous species** increased further slightly (+100 trees/ha) with a large standard deviation (1600). The following parameters can explain about 30% of the variation:

- altitude (+)
- frequency of soil damages (+)
- tree density in 1995 (-)

The density of **broad-leafed pioneer species** decreased slightly about 80 trees/ha at average, but the standard deviation was large again (1700). About half of the variation of the density development (R^2=0.52) can be explained by

- crown cover 1995 (-)
- length of machine tracks (+)
- soil moisture (-)

The negative sign of the tree density in 1995 in case of coniferous species and of the crown cover in case of pioneers show that the losses due to competition have began at sample areas where the timber was removed. In contrast the sample areas with remained timber are not completely covered with trees in 2000, at least not to degree that causes losses due to competition as the positive sign of tree density in 1995 show.

4 Discussion

The negative impacts on the survival of the planted trees which were determined at the level of single trees showed not much impact on the development of the tree density at the stand level. The most sample areas with artificial regeneration were covered very densely already in 1992 so that the losses due to competition started at once. Apparently lesser densities of planted trees would have been sufficient. The amount of additional natural regeneration of coniferous trees during the first years couldn't have been foreseen. Only a very high tree density at the beginning ensures few additional natural regeneration of spruce or pine. At least soil damages should be avoided, if additional natural regeneration of coniferous and broad-leafed pioneer tree species are not desired.

The Bavarian state forest service recommends a conversion of coniferous forests damaged by storm towards a composition containing more broad-leafed trees provided deciduous forests represent the natural vegetation. The development of the sample areas provided for natural regeneration show that this conversion doesn't take place within a short time, if there isn't much regeneration of broad-leafed terminal tree species at the beginning. In fact a complete natural regeneration is possible. When timber was removed the regeneration was faster. When timber wasn't removed the regeneration may be not complete even 10 years after the damage. But pioneer tree species and coniferous trees dominate the composition of the young forests. If a quick conversion towards broad-leafed terminal tree species is desired, artificial regeneration is necessary.

5 References

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