GROWTH AFTER BIOMASS REMOVAL DURING PRE-COMMERCIAL THINNING

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Abstract: *Following the "energy crisis" in the 70ies, several studies on energy from forest biomass suggested to harvest whole trees rather than only stem wood. Consequently ecologists at that time warned from removing needles/leaves, twigs and branches during harvesting operations and calculated the amount of nutrients thus removed from the ecosystem. The question if from these nutrient removals, growth reductions will follow, is answered in experiments, established on three Austrian sites between 1977-1979 in young Norway spruce stands. Three treatments with 4 replications each were applied:. In the control, the felled trees were left on the forest floor, in another treatment, the whole felled trees were removed immediately, and in a third treatment, the trees were removed, including branches and twigs one year later, thus leaving the needles in the stand. After three years, a growth reduction of about 10% was found, which gradually increased to more than 20% in the average after 20 years.*

1. Introduction

Following the "energy-crisis" of the 70ies, many studies on the supply of energy wood were performed. Besides the idea of energy plantations, suggestions were made to enhance the wood supply from forest operations, which would have been recommended anyhow from silvicultural reasons, by reducing the minimum dimensions and by comprising more tree fractions than stem wood only.

About at the same time, the results of thinning experiments showed that the effect of thinnings was the larger, the earlier and the heavier the thinnings were. Heavy pre-commercial thinnings enhanced the stability of the stands against snow breakage, and very efficiently increased the dimensions of the trees finally harvested, without serious growth reductions, if later on the thinning intensity and severity was decreased (e.g. Abetz, 1975, 1984; Pollanschütz, 1971, 1974a, 1980; Chroust, 1980). But these early thinnings resulted in only small harvested dimensions, and thus forest owners hesitated to apply these "new" thinning schedules. In this situation, an increase in the amount of harvested biomass, together with the expectation of higher prices due to increasing energy prices, could encourage forest owners to perform the silviculturally desired early and heavy thinnings.

On the other hand, ecologists warned that by harvesting tree fractions, the nutrient concentrations of which were much higher than those of stem wood only, would result in nutrient deficiencies (e.g. Kreutzer, 1979). Even comparisons with former litter raking were drawn (Krapfenbauer, 1983). While the harvest in biomass through whole-tree harvesting can be increased by about 60%, the respective increase in nutrient removals will be 400 to 900% (Krapfenbauer and Buchleitner, 1981).

Thus two competing concepts were on stage: Early and heavy thinnings, made more profitable by whole-tree harvest, hazarding the consequence of nutrient impoverishment, or refraining from these early thinnings and hazarding snow breakage and accepting smaller final harvesting dimensions at the end of the rotation.

While at that time a large amount of work was done, proving and quantifying the nutrient removals from whole-tree harvesting (e.g. Yilderim, 1978; Kreutzer, 1979; Ulrich, 1981, Krapfenbauer and Buchleitner, 1981; Lick, 1989), their effect on the growth of the remaining trees was well assumed (Krapfenbauer, 1983) but not yet experimentally proven.

The objective of the presented studies was to test, if the removal of different fractions of the trees in the course of otherwise normal thinning operations will lead to changes in the growth rates of the remaining stands.

2. Methods

2.1 The experiments

In three young Norway spruce (*Picea abies* L. Karst.) stands, a pre-commercial thinning was performed (Figure 1, Table 1 and 2).

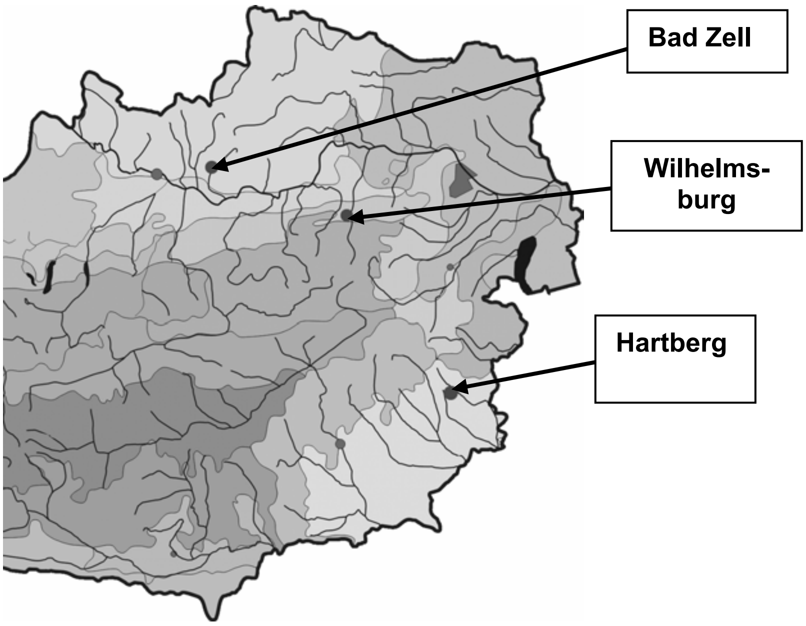


Figure 1: The locations of the three experiments in eastern Austria

The three experiments differed considerably in terms of the site class, which is well reflected by the site descriptors, climate, bedrock, soil type, humus layer thickness, elevation, precipitation and mean annual temperature (Table 1).

Table 1: Site description of the three stands, where the experiments were established. Site class is mean annual increment at age 100 [m³ha^{-1}a^{-1}], estimated by the appropriate yield table (Marschall, 1975)

	Wilhelmsburg	Hartberg	Bad Zell
Elevation (m a.s.l.)	380	350	600
Mean precipitation [mm]	880	750	780
Mean annual temperature °C	8.0	8.2	7.2
Bedrock	Flysch sandstone	Loess and diluvial clays	Gneiss
Soil type	Pseudogley	Pseudogley	Semipodzol
Humus layer [cm]	0.5	2.2	5.4
Site class	18	10	8

A moderate nutritional deficiency in nitrogen is indicated by the element concentration in the Hartberg and in the Bad Zell experiment (Table 2).

Table 2: Macro-nutrient concentrations in the one year old needles [% dry mass], compared with the threshold for deficiency according to Stefan (1985)

	N	P	K	Ca	Mg
Wilhelmsburg	1.46	0.14	1.22	0.46	0.12
Hartberg	1.18	0.14	0.98	0.37	0.15
Bad Zell	1.21	0.18	0.93	0.38	0.11
Deficiency limit	1.31	0.11	0.33	0.01	0.07

These pre-commercial thinnings together with the establishment of the establishment of the experiments were performed in 1981 in Wilhelmsburg, in 1982 in Hartberg and in 1983 in Bad Zell.

According to Pollanschütz (1974b, 1980), these first pre-commercial thinnings took place at a mean height between 5 and 8 m. Since the experiments in Wilhelmsburg and in Bad Zell originated from plantations, the thinnings were performed geometrically, leaving the mean height and the mean diameter approximately constant, only reducing the stem number by about 50%. The Hartberg experiment originated from natural regeneration, with very high stem numbers. Thus the reduction in stem number was much higher than in the other experiments, and the thinning was one from below, thus increasing the mean height and the mean diameter of the remaining stand distinctly (Table 3).

Table 3: The pre-commercial thinning in the three experiments
N/ha is the stem number per hectare of all trees larger than 1.3 m,hm is Lorey's mean height, and dg is the quadratic mean diameter.

	Before thinning			After thinning		
Experiment	N/ha	hm [m]	dg [cm]	N/ha	hm [m]	dg [cm]
Wilhelmsburg	5,014	7.5	7.5	2,407	7.6	7.5
Hartberg	14,400	6.6	5.2	4,244	8.3	7.1
Bad Zell	4,809	5.9	6.2	2,475	6.0	6.3

In each of these three stands, 12 plots were established, each of them containing at least 50 remaining trees larger than 1.3 m after the thinning.

The three treatments, applied randomly to the 12 plots in each experiment were:

Control: The whole felled trees were left on the floor, only in the Wilhelmsburg experiment, the stemwood (without needles and branches and without the top of the tree up to 5 cm) was removed too.

Whole-tree harvest: The whole felled trees including branches, twigs and needles were removed immediately after the felling.

Whole-tree "dry": Here the felled trees were left in the stand for one year, in order to shed the needles, and only then the rest of these trees (stemwood and branches and larger twigs) were removed, thus leaving the needles and small twigs in the stand.

From all trees left in the plots the co-ordinates, the breast height diameter (dbh) and the tree height were measured at the beginning of the experiment and further on in three years intervals until a dominant height of about 15 m was reached. Then in each location a selective thinning was performed, in the way that about 300 future crop trees per ha were selected (Abetz, 1975) and released from their competitors according to an A-value of 6 (Johann, 1982). This means that for each future crop tree its competitors were removed if

$$Dist \le \frac{h_{\text{future crop tree}}}{dbh_{\text{future crop tree}}} \cdot \frac{dbh_{competitor}}{A}$$

with ***Dist***, the distance between the future crop tree and the competitor, ***h*** the tree height, ***dbh*** the breast height diameter and ***A*** characterizing the remaining competition in a way that a large A means strong, and a small A weak competition.

These selective thinnings took place in 1992 in Hartberg and in one part of the Bad Zell experiment, in 1993 in Wilhelmsburg, and in 1996 in the second part of the Bad Zell experiment.

Again the removed trees were treated according to the three experimental treatments, control (at this time in all experiments the stemwood without needles and branches was removed), whole-tree harvest, and whole-tree harvest "dry".

After these selective thinnings and in 5 year periods afterwards, again all trees in the plots were measured in dbh and height.

2.2 Computational and statistical evaluation

For all trees in the plots the stem volume was calculated from the dbh-, and height measurements. For trees with dbh > 10cm the stem form factor equation of Pollanschütz (1974b) was used. For trees with 5 cm < dbh ≤ 10 cm the equation of Schieler (1988) was used, which was developed in a way that for dbh=10 both equations, that of Schieler (1988) and that of Pollanschütz (1974b) gave exactly the same volume. For the few trees with dbh ≤ 5 cm, the stem volume equation of Hafellner (1985) was used. The individual tree increment was calculated as the difference of two successive volumes. The volumes and the volume increment per hectare in each plot was calculated from the sum of the individual tree increments in the plot and the plot size.

In all three experiments, the mean initial stem volume did not differ significantly by treatment, but varied to some extent. Because the initial tree volume and the volume increment of the individual trees were highly correlated within each plot, within-plot regression analysis was used, to adjust the plot increment for the mean initial tree volume of the experiment (Figure 2). For each plot and each period, the linear relationship between the individual tree volume increment and the initial tree volume was estimated by linear regression. With this regression, the adjusted increment of the plot was calculated by introducing the average initial volume of the whole experiment of those trees which were alive in this period:.

$$iv_{i,j,adjusted} = a_{i,j} + b_{i,j} \cdot v_{j,initial}$$

$iv_{i,j,adusted}$ is the adjusted volume increment of the i^{th} plot in the j^{th} period; $a_{i,j}$ and $b_{i,j}$ are the intercept and the regression coefficient of the i^{th} plot in the j^{th} period, and $v_{j,initial}$ is the average initial volume of all trees in the experiment, which were alive in the j^{th} period (Figure 2).

In order to calculate the adjusted increment of the plot in the j^{th} period, the adjusted average volume increment $iv_{i,j,adusted}$ was multiplied by the average stem number per hectare of the trees alive in this period in the whole experiment.

By this procedure, the volume increments of the plots and periods were adjusted for initial treatment differences, in order to not confuse them with treatment effects. These adjusted per hectare increments were then analysed further by analyses of variance: For each period and each experiment separately, an analysis of variance, and Scheffee-tests were used to test for treatment effects, and finally for each period a two-way analysis of variance and Scheffee-tests were calculated to test for main effects of the treatments, main effects of the locations, and interactions between location and treatment, in order to see, if the treatment effects differed by location or not.

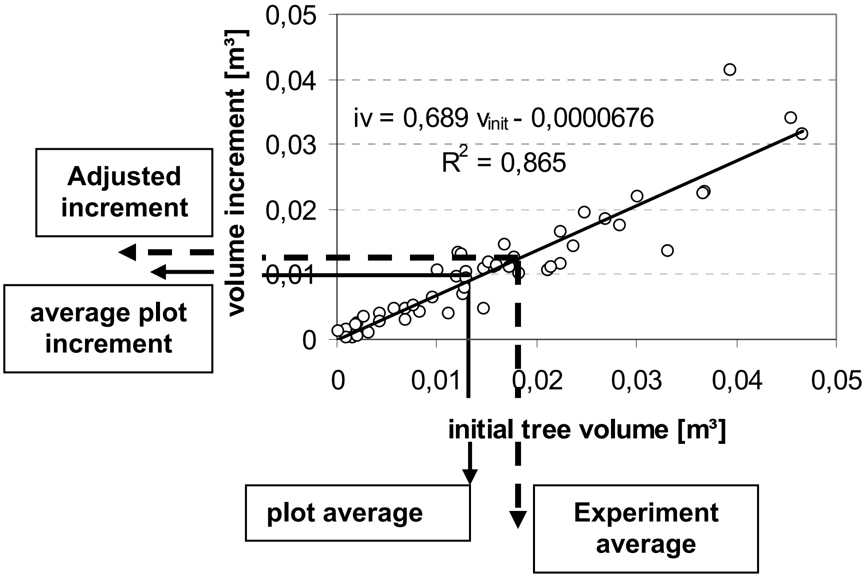
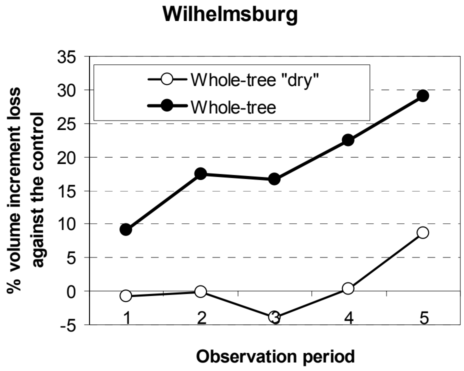


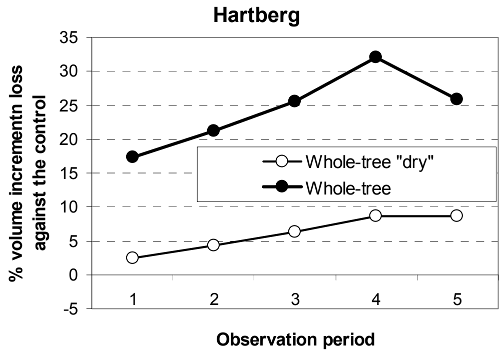
Figure 2: Adjusting the average plot increment for the average initial volume of the experiment

3. Results

The individual results for the locations have been already evaluated by Brunner (2002) for the Wilhelmsburg experiment, by Gugganig (2002) for the Hartberg experiment and by Hauser (2003) for the Bad Zell experiment. The relative increment losses in percent of the increment of the control follow a quite similar pattern in the Wilhelmsburg-, and in the Hartberg experiment, and a different one in the Bad Zell experiment (Figure 3). In the Wilhelmsburg and in the Hartberg experiment, the treatment where the needles were left in the stand, did not exhibit any significant growth reductions, while the whole-tree harvest showed serious and increasing increment losses. In the Bad Zell experiment, both treatments showed considerable and increasing increment losses, but did not differ between each other.

Following the question if these results can be generalized, i.e. if there exists a significant location × treatment interaction, the two way ANOVAs (Table 4), shows that there is a main effect of the treatments, namely between the whole-tree harvest and the control (Figure 4), but no significant location × treatment interaction in any observation period. This means that in most of the observation periods, and as an average over the 20 years of observation, there is a significant effect of the whole-tree harvest on the volume increment. But this effect does not differ between the experiments (no interaction).





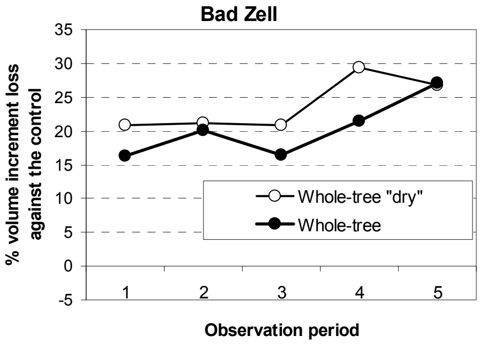


Figure 3:
The relative difference in volume increment between the whole-tree, and the whole-tree „dry“ treatment, against the control in the three experi-ments (locations).

Table 4: Error probabilities for the hypothesis, that there is no effect of the treatment, of the location and their interaction. Error probabilities < 0.05 indicate significant effects.

	Observation period					
	1	2	3	4	5	All
Treatment	0.1719	0.0195	0.0829	0.0299	0.0229	0.0307
Location	0.0001	0.0023	0.0100	0.7865	0.3741	0.1075
Treatment×Location	0.6688	0.6148	0.6847	0.4842	0.8596	0.6714

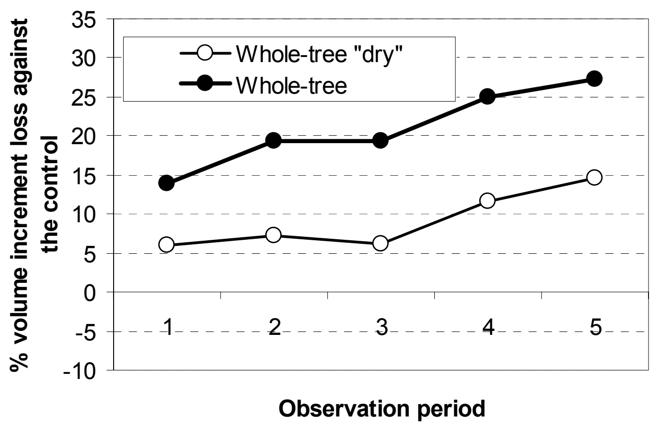


Figure 4: The relative difference in volume increment between the whole-tree, and the whole-tree „dry“ treatment, against the control as an average over all three locations.

4. Discussion and conclusions

Since the first publication on these experiments after the first three year observation period (Sterba, 1988), several only a few other authors dealt with similar questions. Mård (1998) found in a 20 to 30 year old mixed stand of Norway spruce and predominant birch, no significant loss in volume increment after 4 years, when the birch trees were harvested including their branches and twigs in comparison to the treatment, where the felled birches were left in the stand. In two stands of 25 and 34 year age respectively, Nord-Larsen (2002) found 5 to 18% increment losses after 5 years, when the pre-commercial thinning was performed as a whole-tree harvest, compared with only removing the stemwood. During the next 6 year period, he found no increment losses anymore. In contrast to that, a thinning from below in several 30 to 50 year old Norway spruce stands resulted in not significant increment losses in the first 5 years, when performed as whole-tree harvests, compared to stemwood removal only. But in the next 5 year period a significant increment loss of 9% was found (Jacobson et al., 1996, 2000).

Thus the result of our experiments, that there are significant increment losses through whole-tree harvest, if it includes the needles, is found quite in conformity with other reports. But the magnitude of these losses is rather surprising, although from the methodological point of view, these results are reliable. The idea that increment losses are higher in stands with better site classes, as it is the case at least with the Wilhelmsburg and the Hartberg experiment, is well supported by Egnell and Leijon (1997), Jacobson et al. (2000) and Nord-Larsen (2002). Kimmins (1977) points out that the nutritional status of trees and thus increment changes are mainly affected by the speed of the nutrient cycle. The thin humus layer of the investigated sites (Table 1) indicates – at least again in the first two locations – such a fast nutrient cycle. A third reason, why the increment losses are so high in the investigated experiment, is the amount of the removals. While all the other reported experiments had been thinned from below, or only a few pre-dominant birches had been removed, in our pre-commercial thinnig at least half of the biomass has been removed.

Altogether it must be concluded, that on the respective sites, heavy pre-commercial thinnings and later selective thinnings in a way that the felled trees including their branches and needles are removed, lead to losses in volume increment of more than 20 % in the average compared with a treatment, where the felled trees are left in the stand or only the stemwood is removed.

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6. References

Abetz, P. (1975) Eine Entscheidungshilfe für die Durchforstung von Fichtenbeständen, Allgemeine Forstzeitschrift. 36, 666-668.

Abetz, P. and Unfried, P. (1984) Fichten-Standraumversuche im Forstbezirk Riedlingen/Donau, Allgemeine Forst- u. Jagdzeitung. 155, 89-109.

Brunner, H. (2002) Die Auswirkungen von Biomasse- und Nährstoffentzügen bei Durchforstungen auf den Zuwachs – Versuch Wilhelmsburg. Diploma Thesis, Universität für Bodenkultur Wien.
Chroust, L. (1980) Erziehung von den durch Schnee und Wind gefährdeten Fichtenbeständen, Schriften aus der forstlichen Fakultät der Universität Göttingen. 67, 206-213.

Egnell, G. and Leijon, B. (1997) Effects of different levels of biomass removal in thinning on short-term production of Pinus sylvestris and *Picea abies* stands, Scandinavian. Journal of Forest Research, 12, 17-26.

Gugganig, H. (2002) Auswirkungen von Biomassenentzügen bei Durchforstungen auf den Zuwachs von Beständen in der Oststeiermark. Diploma Thesis, Universität für Bodenkultur Wien.

Hafellner, W. (1985) Studie über die Entwicklung und Struktur der forstlichen Biomasse in Fichtendickungen nach unterschiedlich starken Stammzahlreduktionen. Diploma Thesis, Universität für Bodenkultur Wien.

Hauser, B. (2003) Auswirkungen von Biomassenentzug bei Durchforstungen auf den Zuwachs von Fichtenbeständen – Versuch Bad Zell. Diploma Thesis, Universität für Bodenkultur Wien.

Jacobson, S.; Kukkola, M.; Mälkönen, E.; Tveite, B.; Möller, G. (1996) Growth response of coniferous stands to whole-tree harvesting in early thinnings, Scandinavian. Journal of Forest Research, 11, 50-59.

Jacobson, S.; Kukkola, M.; Mälkönen, E.; Tveite, B, (2000) Impact of whole-tree harvesting and compensatory fertilization on growth of coniferous thinning stands, Forest Ecology and Management, 129, 41-51.

Johann, K. (1982) Der "A-Wert" – ein objektiver Parameter zur Bestimmung der Freistellungsstärke von Zentralbäumen, Deutscher Verband Forstl. Forschungsanstalten, Sektion Ertragskunde. Weibersbrunn, 146-158.

Kimmins, J. P. (1977) Evaluations of the consequences for future tree productivity of the loss of nutrients in whole-tree harvesting, Forest Ecology and Management, 1, 169-183.

Krapfenbauer, A. (1983) Von der Streunutzung zur Ganzbaumnutzung, Centralbatt. für das gesamte Forstwesen, 100,143-174.

Krapfenbauer, A. and Buchleitner, E. (1981) Holzernte, Biomassen- und Nährstoffaustrag, Nährstoffbilanz eines Fichtenbestandes, Centralbatt. für das gesamte Forstwesen, 98, 193-223.

Kreutzer, K. (1979) Ökologische Fragen zur Vollbaumernte, Forstwissenschaftliches Centralblatt, 98, 298-308.

Lick, E. (1989) Untersuchungen zur Problematik des Biomassen- und Nährelemententzuges bei der Erstdurchforstung eines zentralpinen Fichtenbestandes. Disseration. Universität für Bodenkultur Wien.

Mård, H. (1998) Short-term growth effects of whole-tree harvesting in early thinnings of birch (Betula sp.) and *Picea abies*, Scandinavian. Journal of Forest Research, 13, 317-323.

Marschall, J. (1975) Hilfstafeln für die Forsteinrichtung. Österr. Agrarverlag, Wien.

Nord-Larsen, T. (2002) Stand and site poductivity response following whole-tree harvesting in early thinnings of Norway spruce, Biomass and Bioenergy, 23, 1-12.

Pollanschütz, J. (1971) Durchforstung von Stangen- und Baumhölzern, Forstarchiv, 42, 257-259.

Pollanschütz, J. (1974a) Erste ertragskundliche und wirtschaftliche Ergebnisse des Fichten-Pflanzweite-versuches Hauersteig, In: Egger, G. (ed.) 100 Jahre Forstliche Bundesversuchsanstalt . Forstliche Bundesversuchsanstalt Wien.

Pollanschütz, J. (1974b) Formzahlfunktionen der Hauptbaumarten Österreichs, Allgemeine Forstzeitung, 85, 191-194.

Pollanschütz, J. (1980) Erfahrungen aus der Schneebruchkatastrophe 1979, Allgemeine Forstzeitung, 91, 123-125.

Schieler, K. (1988) Methodische Fragen im Zusammenhang mit der österreichischen Waldinventur. Diploma Thesis, Universität für Bodenkultur Wien.

Stefan, K. (1985) Ergebnisse der Bioindikator-Analysen, In: Führer, E. (ed.) Forschungsinitiative gegen das Waldsterben. Bundesministerium für Wissenschaft und Forschung, Wien, 61-71.

Sterba, H. (1988) Increment Losses by Full-Tree Harvesting in Norway Spruce (*Picea abies*), Forest Ecology and Management, 24, 283-292.

Ulrich, B. (1981) Destabilisierung von Waldökosystemen durch Biomassennutzung, Forstarchiv, 52, 199-203.

Yilderim, M. (1978) Der Nährstoffexport aus Fichtenreinbeständen in Abhängigkeit vom Holzernte-verfahren. Dissertation. Universität Göttingen.